Tropical root and tuber crops

Production, perspectives and future prospects

ISSN 0259-2517

FAO
PLANT
PRODUCTION
AND PROTECTION
PAPER

126

Food
and
Agriculture
Organization
of
the
United
Nations

Tropical root and tuber crops

Production, perspectives and future prospects

FAO
PLANT
PRODUCTION
AND PROTECTION
PAPER

126

by
Prof. I.C. Onwueme
Federal University of Technology
Owerri, Nigeria
Dr W.B. Charles
Root and Tuber Crop Officer
Crop and Grassland Service
FAO, Rome

Food
and
Agriculture
Organization
of
the
United
Nations

Rome, 1994

The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

M-11
ISBN 92-5-103461-3

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying or otherwise, without the prior permission of the copyright owner. Applications for such permission, with a statement of the purpose and extent of the reproduction, should be addressed to the Director, Publications Division, Food and Agriculture Organization of the United Nations, Viale delle Terme di Caracalla, 00100 Rome, Italy.

© FAO 1994

Copyrighted material

PREFACE

This publication was prepared under an FAO's Author's Contract by Professor I.C. Onwueme, School of Agriculture and Agricultural Technology, Federal University of Technology, Owerri, Nigeria, with technical supervision of W.B. Charles, Root and Tuber Crop Officer, Plant Production and Protection Division (AGP).

The major tropical tuber crops (cassava, yams, sweet potatoes and aroids) constitute an important group of stable crops for millions of people throughout the tropics. In sub-Saharan Africa, South America, the Caribbean, Asia and the South Pacific Region, one or other of these crops attains prominence as a major calorie supplier in the population's diet.

The developing countries, which constitute 62.8 percent of the global population, are reported to produce over 350.5 million tonnes of root and tuber crops. Yet for all their importance, these crops have suffered considerable neglect from researchers, policy makers, and even the educational authorities. Both human and financial resources devoted to national, regional and international research and development institutions and agencies are minimal. Also, they are only very cursorily covered in the curricula of various schools and universities; thereby perpetuating and exacerbating their neglect at the policy level.

The document focuses attention on the significant role of these crops in the economy of developing countries. It is intended to assist Government officials and policy makers in acquiring resources for research and development and is directed towards Ministries of Planning and Agriculture, their advisers and donors. It points to the need for strengthening national policies to support research, training and extension programmes on a multidisciplinary basis for the development of new technologies that can meet farmers' needs and consumers' demand.

It is, therefore, felt that the document will be of interest to students, agronomists, economists and administrators in FAO member countries for the promotion of these selected traditional food crops, for the alleviation of food shortages and for raising the income of the rural poor.

This One
C8H3-APH-R9YN
Copyrighted material

TABLE OF CONTENTS

1. TROPICAL TUBERS IN THE FOOD POLICY CONTEXT 1

SECTION A: CASSAVA

2. BOTANY AND ECOLOGY OF CASSAVA 9
2.1 CLASSIFICATION 9
2.2 ECO-PHYSIOLOGY OF CASSAVA 9
2.3 PHENOLOGY OF CASSAVA 11
2.4 THE ROOT AND THE TUBER 12
2.5 THE STEM AND LEAVES 13
2.6 FLOWER, FRUIT, AND SEED 15

3. CULTIVATION OF CASSAVA 16
3.1 PLANTING MATERIAL 16
3.1.1 The rooting of cassava cuttings 16
3.1.2 Length of cutting 16
3.1.3 Age of cutting 17
3.1.4 Selection and handling of cuttings 18
3.2 ORIENTATION OF THE CUTTING 18
3.3 THE SEEDBED 20
3.4 SPACING 20
3.5 TIME OF PLANTING 21
3.6 MECHANIZED PLANTING 21
3.7 WEED CONTROL 21
3.8 FERTILIZING 22
3.9 YIELDS 24
3.10 CROPPING SYSTEMS FOR PRODUCING CASSAVA 25

4. DISEASES AND PESTS OF CASSAVA 28
4.1 CASSAVA MEALY BUG 28
4.2 CASSAVA GREEN MITE 28
4.3 CASSAVA MOSAIC VIRUS DISEASE 28
4.4 CASSAVA BACTERIAL BLIGHT 29

4.5 OTHER DISEASES AND PESTS 31

5. **HARVESTING, STORAGE AND UTILIZATION OF CASSAVA** 32
5.1 HARVESTING 32
5.2 UTILIZATION 34
5.2.1 Composition of the cassava tuber 34
5.2.2 Cyanide in cassava 34
5.2.3 Utilization of the fresh tuber 36
5.2.4 Toasted cassava meal: *gari*, *farinha*, etc. 37
5.2.5 Meal of retted cassava 39
5.2.6 Cassava flour 40
5.2.7 Cassava chips and pellets 40
5.2.8 Cassava starch 40
5.2.9 Cassava leaves 41

6. **SOCIO-ECONOMIC CHARACTERISTICS: PERSPECTIVE, PROBLEMS, AND FUTURE PROSPECTS FOR CASSAVA** 42
6.1 GLOBAL PRODUCTION 42
6.2 CHARACTERISTICS OF THE CASSAVA DELIVERY SYSTEM 42
6.2.1 Labour requirement 42
6.2.2 Heavy calorie yield 43
6.2.3 Hardy plant characteristics 43
6.2.4 Ideal planting material 43
6.2.5 Cheap, convenient staple 43
6.2.6 International trade 44
6.2.7 Mechanization 44
6.3 OUTSTANDING PROBLEMS OF CASSAVA 44
6.4 FUTURE PROSPECTS AND THE ROLE OF RESEARCH 46

SECTION B: YAMS

7. **BOTANY AND ECOLOGY OF YAMS** 51
7.1 KINDS OF YAM 51
7.2 MORPHOLOGY AND ANATOMY OF YAMS 55
7.2.1 The root 55

7.2.2 The stem 56
7.2.3 The leaf 57
7.2.4 The flower, fruit and seed 57
7.2.5 The bulbil 58
7.4 PHENOLOGY OF YAMS 61

8. **THE YAM TUBER: FORM AND FUNCTION** 63
8.1 TUBER FORM 63
8.2 TUBER FUNCTION 64
8.2.1 Tuber formation in yam 64
8.2.3 Tuber sprouting and dormancy 67

9. **CULTIVATION OF YAMS** 71
9.1 CLEARING 71
9.2 TILLAGE AND SEED-BED PREPARATION 71
9.2.1 Mounding 71
9.2.2 Flat Planting (Holes) 72
9.2.3 Ridging 73
9.3 PLANTING MATERIAL 74
9.3.1 Sett weight 74
9.3.2 Sett type 75
9.3.3 The yam minisett technique - planting with whole tubers 76
9.3.4 Planting with conventional setts (from previous season's harvest) 77
9.3.5 Pre-sprouting of yam 78
9.3.6 Exclusive use of heads 80
9.3.7 Planting with bulbuls 81
9.4 TIME OF PLANTING 81
9.5 SETT PLACEMENT 82
9.5.1 Spacing 82
9.5.2 Depth of sett placement 82
9.5.3 Sett orientation 83
9.6 MULCHING 83
9.7 STAKING 84
9.8 WEED CONTROL 85
9.9 FERTILIZING 86
9.10 CROPPING SYSTEMS FOR PRODUCING YAMS 88

10. DISEASES AND PESTS OF YAMS 90
10.1 THE YAM BEETLE 90
10.2 YAM ANTHRACNOSE 90
10.3 NEMATODES 90
10.4 YAM VIRUS COMPLEX 91
10.5 TUBER ROTS 91

11. HARVESTING, STORAGE AND UTILIZATION OF YAMS 92
11.1 HARVESTING 92
11.1.1 Single-harvesting 92
11.1.2 Double-harvesting 92
11.1.3 Comparison of single-harvesting and double harvesting 94
11.1.4 Yields 95
11.1.5 Prospects of mechanical harvesting 95
11.2 STORAGE 96
11.2.1 Storage conditions 96
11.2.2 Storage Structures 97
11.3 UTILIZATION 98
11.3.1 Chemical composition 98

12. SOCIO-ECONOMIC CHARACTERISTICS: PERSPECTIVES, PROBLEMS AND FUTURE PROSPECTS 103
12.1 PROBLEMS IN THE YAM DELIVERY SYSTEM 103
12.1.1 Excessive quantity of planting material 103
12.1.2 Laboriousness 104
12.1.3 Long growing season 104
12.1.4 Low yields 105
12.1.5 Storage problems 106
12.1.6 Consumer preference for large tubers 107
12.1.7 Difficulties of yam improvement 108
12.1.8 Competition from cassava 108
12.2 GLOBAL PRODUCTION 108
12.3 ECONOMIC CHARACTERISTICS OF THE DELIVERY SYSTEM 109
12.4 YAM FESTIVALS 110
12.5 FUTURE PROSPECTS: THE ROLE OF RESEARCH 112

SECTION C: SWEET POTATO

13. BOTANY AND ECOLOGY OF SWEET POTATO 115
13.2 CLASSIFICATION 115
13.3 ECO-PHYSIOLOGY OF SWEET POTATO 115
13.4 PHENOLOGY OF SWEET POTATO 116
13.5 MORPHOLOGY AND ANATOMY 117
13.5.1 The root system 117
13.5.2 The tuber 117
13.5.3 Stem and leaves 119
13.5.4 The flower 120
13.5.5 Fruit and seed 120

14. CULTIVATION, HARVESTING AND STORAGE OF SWEET POTATO 122
14.1 TILLAGE AND SEED-BED PREPARATION 122
14.2 PLANTING MATERIAL 122
14.3 PLANTING 124
14.4 WEED CONTROL 124
14.5 FERTILIZING 125
14.6 CROPPING SYSTEMS 126
14.7 HARVESTING 126
14.8 CURING AND STORAGE 127

15. DISEASES AND PESTS OF SWEET POTATO 129
15.1 THE SWEET POTATO VIRUS DISEASE COMPLEX (SPVDC) 129
15.2 THE SWEET POTATO WEEVIL (*CYLAS* SPP.) 129
15.3 BLACK ROT 130
15.4 SCURF, FUSARIUM WILT 131
15.5 NEMATODES 131

16. UTILIZATION, SOCIO-ECONOMIC PERSPECTIVE AND FUTURE PROSPECTS 132
16.1 COMPOSITION 132
16.2 UTILIZATION 133
16.2.1 Utilization of the fresh tuber 133

16.2.2. Processed forms for human consumption 133
16.2.3 Sweet potato as animal feed 133
16.2.4 Industrial uses 133
16.2.5 Leaf consumption 133
16.3 SOCIO-ECONOMICS OF SWEET POTATO 134
16.3.1 Global production 134
16.3.2 Characteristics and future of the delivery system 134

SECTION D: EDIBLE AROIDS

17. BOTANY AND ECOLOGY OF EDIBLE AROIDS 139
17.1 KINDS OF EDIBLE AROIDS 139
17.2 CLASSIFICATION AND BOTANY OF TARO 139
17.3 CLASSIFICATION AND BOTANY OF TANNIA 141
17.4 ECOLOGY AND PHENOLOGY OF COCOYAMS 142

18. CULTIVATION OF COCOYAMS 144
18.1 LAND PREPARATION FOR COCOYAMS 144
18.2 PLANTING MATERIAL 144
18.3 TIME OF PLANTING 145
18.4 SPACING 145
18.5 METHOD OF PLANTING 146
18.6 WATER MANAGEMENT IN COCOYAM CULTIVATION 147
18.7 WEED CONTROL 147
18.8 FERTILIZING TARO 148
18.9 FERTILIZING TANNIA 149
18.10 CROPPING SYSTEMS FOR PRODUCING COCOYAMS 150

19. HARVESTING, STORAGE, DISEASES AND PESTS OF COCOYAMS 151
19.1 HARVESTING AND YIELDS 151
19.2 STORAGE 152
19.3 DISEASES AND PESTS 152
19.3.1 The root rot blight complex or Taro soft rot 152
19.3.2 Root-knot nematode (*Meloidogyne* spp.) 153
19.3.3 Dasheen mosaic virus disease 153

19.3.4 Taro leaf blight 153
19.3.5 Sclerotium rot 154
19.3.6 Cladosporium leaf spot 154
19.3.7 Insect pests 154

20. UTILIZATION, SOCIO-ECONOMIC PERSPECTIVE AND FUTURE PROSPECTS 156
20.1 NUTRITIONAL VALUE OF TARO 156
20.2 NUTRITIONAL VALUE OF TANNIA 157
20.3 UTILIZATION OF TARO AND TANNIA 158
20.3.1 Acridity in cocoyams 158
20.3.2 Fresh corms, cormels and leaves 158
20.3.3 *Poi* 158
20.3.4 Flour 158
20.4 PROBLEMS OF THE COCOYAM DELIVERY SYSTEM 159
20.5 SOCIO-ECONOMIC CHARACTERISTICS AND FUTURE PROSPECTS 159
20.5.1 Global production 159
20.5.2 Perspective and future prospects 160

APPENDIX I - TABLES
APPENDIX II - FIGURES
REFERENCES
INDEX

LIST OF FIGURES

1. Growth habit of cassava
2. General morphology of the cassava tuber
3. Cassava tubers
4. Transverse section of the cassava tuber
5. Inflorescence of cassava
6. Cassava chips for human consumption
7. The yellow yam, *Dioscorea cayenensis*
8. *Dioscorea esculenta*
9. Bulbils of *Dioscorea bulbifera*
10. Phases in the yam growth cycle
11. Yam tuber morphology
12. Transverse section of the yam tuber
13. Four stages (a, b, c, d) in the sprouting of the yam tuber. B, newly differentiated bud; C, cork layer; M, layer of meristematic cells; P, parenchyma cells with very little stored starch; SP, storage parenchyma with much stored starch; V, vascular bundles; (after Onwueme, 1973)
14. Effect of duration in storage on the time required for the yam tuber to sprout (adapted from Onwueme, 1975a)
15. Setts of *Dioscorea alata* after dry presprouting
16. Methods of staking yams
17. *Dioscorea esculenta* tubers showing root knot nematode damage
18. Yellow yam infected with the shoe-string virus disease.
19. Soft rot of yam
20. Yam tuber from the second harvest
21. Effect of timing of the first harvest on the yield of the second harvest of yams. The later the first harvest (A), the lower the yield of the second harvest(B). C indicates the sum of the yields from the first and second harvests (after Onwueme, 1977b)
22. Stages of tuber formation in sweet potato
23. Transverse section of the sweet potato stem
24. Planting sweet potato on ridges
25. Taro in the field

26. Corms and cormels of taro
27. Structure of the inflorescences of taro and tannia. The spathe has been opened up to display the spadix in each case
28. Taro (dalo) bundled for sale in Fiji

Chapter 1

TROPICAL TUBERS IN THE FOOD POLICY CONTEXT

The major tuber crops of the world are the potato (*Solanum tuberosum*), sweet potato (*Ipomoea batatas*), cassava (*Manihot esculenta*), yams (*Dioscorea* spp.), and cocoyams (*Colocasia* spp. and *Xanthosoma* spp.). Some of these (cassava, and sweet potato) are root tubers, others (potato and cocoyams) are stem tubers, while yam is intermediate between root and stem tuber. For simplicity all these crops are referred to collectively as tuber crops, a term which, unlike "root crops", does not confer any connotations as to morphological origin.

In all, tuber production in the world in 1990 amounted approximately to 597 million tonnes, made up of 270 million tonnes of potato, 158 million tonnes of cassava, 132 million tonnes of sweet potato, 29 million tonnes of yams and 5 million tonnes of cocoyams (Table 1). Cassava, yams and cocoyams are strictly warm weather crops, and practically all that is produced of these crops comes from the tropics. On the other hand, the tropics account for only about 16% of sweet potato and about 10% of potato that is produced in the world. Sweet potato can be produced in both lowland and highland tropics, while potato in the tropics is, for all practical purposes, confined to isolated alpine locations where the climate is in effect temperate. Partly because of the small percentage that is produced in the tropics, and because of the temperate ecology to which it is confined, the potato is usually not considered among the major tropical tuber crops.

The trend in world production of the tropical tuber crops from 1979 to 1989 indicates that both sweet potato and cocoyams recorded decreases in total production, while yams and cassava showed modest increases (Table 2). Even these increases in yam and cassava production must be seen in light of the fact that their production is prominent in those countries where the population growth rates are high - usually 2 to 3% per annum. Thus even for yams and cassava, the production increases have failed to keep pace with population increases, and the production per capita has definitely declined (de Bruijn and Fresco, 1989). Therefore, the overall per capita production of tropical tubers has stagnated during the 1980s.

Virtually all of the yams and cocoyams produced in the world is used for human consumption. The same is true for tropically-grown sweet potato. Even for cassava, which enters international trade as animal feed, about 70-80% of world production is used for human food. Since these crops are essentially starchy staples, dependence on them can be seen by the percentage of total food calories that each country derives from tuber crops. Table 3 presents the world data for the countries that are most dependent on tuber crops.

The preponderance of countries that are heavily dependent on tubers for food are:

1) Africa, where tubers constitute a crucial part of the diet. Yet this is precisely the continent where food insecurity, at both the household and national levels, has prevailed throughout the 1980s. It is obvious that any attempt to address the food situation on this continent must take full cognizance of the crucial role that the tubers have played for generations and continue to play in the traditional food systems of the population.

2) Oceania also shows a marked dependence on tuber crops. Although the food crisis has not become as critical as in Africa, these countries, like Africa, have fragile developing economies with the most precarious food supply situation.

3) On a global scale, virtually all the countries that are heavily dependent on tuber crops, are the relatively poor ones. Tuber crops therefore generally constitute the "poor people's" food, with all the consequent social, economic and political implications. Even within the producing countries, the consumption of tubers is much greater among the poorer masses than among the richer strata of society.

The position of the tropical tuber crops, even in countries that are heavily dependent on them is unenviable and precarious. The FAO Committee on World Food Security reported in 1986 that there was a "frequent absence of a coherent policy framework for the traditional food sector particularly for roots and tubers" in Africa (FAO, 1986). Tropical tubers suffer severely from lack of attention and policy support from the authorities. There are several reasons for this neglect.

Most of these countries have had a colonial history; heavy emphasis in agricultural development was placed on cash and export crops which could be sent to the colonizing countries. The traditional food crop sector was more or less left to develop on its own. The agricultural policies, infrastructures, and subsidies were tailored for maximizing the production of the cash export crops, while the traditional food crops were neglected. Unfortunately, the tuber crops belonged to the traditional food sector, and did not benefit much from pre-independence agricultural policies.

Even in the post-independence era, the development of the cash crops continued at the expense of the food crops. To worsen matters, international lending and donor agencies appeared more willing to fund cash crop development projects rather than projects dealing with traditional food crops (including tuber crops.). Projects on traditional food crops, despite their high social and political value, had low direct short-term economic value, and proved unattractive to the authorities and the donor agencies.

The background and training of the leaders, policy makers, and technocrats had failed to give recognition to the importance of tuber and other traditional crops, and had dealt almost exclusively on cash crops. This might seem like a minor point, but its multiplier effect is tremendous. A minister or president who, throughout his formal training, had never been made to appreciate the importance of the traditional food sector, is unlikely to generate policies that would ensure the survival and development of that particular sector. Similarly an extension agent whose training ignored the tuber crops, will not feel technically comfortable "extending" knowledge of these crops. He ignores them instead, and concentrates on the crops (usually the cash crops) with which he is technically more familiar. The people he instructs are therefore not trained in the production of tuber crops, and will, in turn, propagate this unawareness to the people they teach.

At this stage it is important to explain that the delivery of the crop from field to consumption should be seen as one single system. It is a continuum that embraces pre-planting operations, planting, tending, harvesting, storing, processing, marketing, culinary preparation, etc; each stage itself constituting a sub-system. Interventions in one part of this *delivery system* can seriously affect other parts of the system, for the better or for the worse. There are also various factors outside the system (e.g. government policies) that can have a very serious impact on the system as a whole, or on various sub-systems within it. Like any chain, the delivery system for the tuber crops is only as strong as the weakest link (sub-system) within it.

The neglect of tuber crops manifests itself in producing countries in several ways.

a) Tuber crop production is usually the least organized and the least supported by extension personnel. Part of the cause is that because of their near subsistence nature, tuber crop production is mostly carried out by smallholder farmers who tend to receive less attention than large-scale farmers. Furthermore, improved technical inputs (fertilizers, pesticides, elite planting materials etc.) are relatively expensive to procure and are preferentially expended on cash crop farmers. An exacerbating factor is the fact that all the tropical tubers are grown from vegetative planting material which is invariably bulky and more difficult to handle or store than the planting materials for cereals and pulses.

b) Because so much of it is used as subsistence food, the processing, storage and marketing facilities for the tuber crops are very poorly organized. It is only in a few countries (Thailand and Brazil) where the tubers have become cash crops that any degree of sophistication has been introduced into organizing these facilities.

c) Many of the producing countries have had and continue to have policies that are detrimental to the production of tuber crops. Partly as a result of neglect of domestic food security, many of these countries have developed a progressively heightened food dependency which is being alleviated by food imports. Unfortunately, the world food market has plenty of cereals on offer, but hardly any tropical tubers. As a result, even in countries where tubers are the traditional foods, the food import has invariably been cereals. This has had the effect of channeling the food tastes of the populace away from tubers and towards cereals which, in some cases, cannot be produced within the consuming countries. The food dependency is thus aggravated. The case of Congo, a country that is traditionally one of the highest per capita tuber consumers in the world, is illuminating. In 1974, the country imported 17,000 tonnes of wheat, a commodity which, for natural ecological reasons, the country cannot produce. By 1985, the wheat importation had increased five fold to 85,000 tonnes (Babasana and Dolou, 1989). Within the country, the wheat consumption was occurring mostly in the cities and was giving rise to an urban class that had lost touch with the traditional tuber diet, while the rural population was still heavily tuber-dependent. Thus the food dependency and the resulting food importation, was not only draining the country's monetary reserves it was also adversely affecting the tuber crops sector, as well as enhancing social stratification within the country. In some cases, an artificially overvalued local currency could cause imported foods to be cheaper than the locally produced equivalents. This actively discourages local production, and adds a further negative twist to the unfortunate predicament of food import dependency.

d) National research efforts in many of the producing countries have hitherto paid scant attention to tuber crops. They concentrate instead on cash crops, for which more money is available. For example in Zambia, where substantial amounts of cassava and sweet potato are produced and consumed, the tuber improvement programme of the Ministry of Agriculture remained practically non-existent until the late 1980s, in a country where maize, sugar, and tobacco have been receiving research attention for decades. While the maize delivery system was also heavily subsidized, the tubers received no such subsidies and were marginalized. Research in tropical tubers in the international research institutes is also a fairly recent phenomenon, and for some of the crops (especially yams and cocoyams) the concentration of research attention has been intermittent and inconsistent. Part of the inconsistency has resulted from difficulty in resolving the perennial dilemma: one point of view is that as these crops are so far behind and so difficult to improve due to neglect, research should be concentrated on them; the other opinion is that as these crops are so far behind and so difficult to improve they should be abbandoned and the scarce research resources devolved on easier crops. Many persons in the tuber-producing countries would concur with the former argument, while some of those who control the purse strings of international research would prefer the latter.

e) The curricula at the primary, secondary, and university levels in many of the tropical tuber producing countries give very little coverage to tuber crops. There is a deplorable scarcity of textbooks and training materials; and the instructors, who themselves have had little training in these crops, are only too happy to bypass the tubers in their lecture schedules. The damage caused by the propagation of this phenomenon has already been highlighted above.

f) International donor and aid agencies have played a critical, if inadvertent, role in the neglect of the tropical tubers in the countries that produce and depend on them. These agencies directly or indirectly regulate the research priorities of the international research institutes, and may at various times see the tropical tuber crops as refractory and expensive to improve. In addition, the agencies are in a position where they have to dispense food aid to food-dependent countries. Like food importation discussed above, food aid is invariably sourced from grain surpluses on the international market. Therefore it has the same effects of slowly altering the food preferences of the tuber-consuming population away from tubers and towards grains. Food brought in as food aid has the characteristic of being very cheap, and consequently lessens the demand and lowers the price of the indigenously produced tubers.

g) Tubers have generally not been developed into diverse processed and culinary forms, partly as a result of limited research and development. This is particularly important if they must continue to be patronized by the urban population who require convenience ("fast") foods. The grains have generally made this transition to readily consumed processed forms, but until the tubers make it, their acceptability and adoption by the urban masses will continue to be limited.

Some of the tropical tubers, especially cassava and sweet potato, exhibit characteristics which enable them to yield reasonably well in dry or low-fertility environments where many of the grains fail. Their food security importance in times or places where grains might fail is therefore extremely high. This very fact has resulted in heightened attention being paid to tuber crops in eastern and southern Africa (e.g. Kenya, Zambia) where the drought of the late 1980s caused the cereal-dependent agriculture to crumble.

In summary, therefore, most of the tubers produced in the world are at present used for human consumption, mainly at the subsistence level. They are critical for both household and national food security, and their importance far outweighs what the production and trade figures might indicate. Unfortunately, the tuber crops have generally been denied the infrastructural support needed for their full promotion and development. Such support includes research, extension, subsidies, and organized production/processing/marketing facilities. Unfortunately, the food policies even in tuber-dependent tropical countries have failed to recognize the importance of the tuber crops in food security, and have devoted little attention and resources to their promotion and improvement. This policy neglect and infrastructural denial have resulted in the low technical level of the delivery systems for tropical tubers. Once their strategic food security importance has been recognized, and appropriate food policies put in place at both the national and international levels, it should not take long to elevate the delivery systems of these crops, and make them competitive within and outside the producing countries.

Section A: Cassava

Chapter 2

BOTANY AND ECOLOGY OF CASSAVA

2.1 CLASSIFICATION

Cassava is a single botanical species, *Manihot esculenta* Crantz (synonymous with *Manihot utilissima* Pohl.). It is a dicotyledonous plant belonging to the botanical family Euphorbiaceae, and, like most other members of that family, contains laticifers and produces latex. The normal cassava plant has a chromosome number $2n = 36$.

The cassava plant originated in north-east Brazil, with perhaps an additional centre of origin in Central America (Rogers, 1963). Its cultivation probably started in these two areas, and today, *Manihot esculenta* does not exist in the wild form. From its places of origin, the plant has spread to various parts of the world and is today cultivated in all tropical regions.

2.2 ECO-PHYSIOLOGY OF CASSAVA

Cassava is a crop best suited to the lowland tropics: a warm, moist climate where mean temperatures range from 25-29°C. Cold climates are detrimental to its growth, and at temperatures below 10°C, growth of the plant is arrested. It cannot withstand frost during its active growing period, so that it can only be profitably grown in regions which are frost-free for at least the time required for the crop to mature. Sprouting of the cutting requires a minimum temperature of 16°C, an optimum of 29°C, and a maximum of 34-38°C (Fukai, 1985). The optimum soil temperature for growing cassava is about 30°C, while the optimum air temperature for the season as a whole is 24-28°C. Heat stress, such as that experienced by cassava growing near gas flares in the Niger delta, results in decreased tuber yield and lower starch content. Low temperatures are often encountered in cassava producing regions such as southern Brazil, the Andean valleys of Colombia, or Luapula Province of Zambia. Such temperatures result in leaf shedding and undue delay of crop maturity, so that it may take up to three years for the crop to mature. Moreover, low temperature appears to reduce the efficiency of formation of beneficial mycorrhizal associations with the roots of cassava (Sieverding, 1988).

Altitude affects cassava production through its moderating effect on temperature. The upper altitudinal limit for cassava production is 1800m (Papua New Guinea), and this corresponds to a mean soil temperature of about 18°C (Bourke, *et al.*, 1984).

The optiminum rainfall for cassava is 100-150 cm per year and well distributed. However, the crop is well adapted to cultivation under drought, and can be profitably grown in areas where the annual rainfall is as low as 50 cm. When moisture availability is low, the cassava plant ceases growth, and sheds some of its older leaves, thereby reducing its total transpiring surface. When moisture is again amply available, the plant quickly resumes growth and produces new leaves. This behaviour makes cassava a valuable crop in places where, and at times when, the rainfall is low, or uncertain, or both. It is only during the first few weeks after planting that the cassava plant is unable to tolerate drought to an appreciable extent.

The roots of cassava remain mainly in the top 1-1.5m of soil, so that its ability to mine water from great depths is quite limited. Moreover, the crop is only able to reduce soil water potential to the range of -10 to -15 bars (Cock & El-Sharkawy, 1988). Thus its ability to survive drought depends mostly on the conservation and efficient use of available water. Apart from leaf shedding and growth reduction, the cassava plant has a unique physiological mechanism for drought survival. First, most cultivars have stomata only on the lower side of the leaf. Secondly, the stomata appear to be sensitive to the water vapour pressure difference (VPD) between the leaf and the surrounding air. The stomata close once this difference reaches a threshold value, even if water stress has not yet developed within the plant. This contrasts with other species which would keep their stomata open and continue to lose water until water stress has developed within the plant. Rather than wait to develop internal water stress, the cassava plant forestalls it by automatic stomatal closure under conditions of high transpirative demand. This feature, combined with leaf area reduction through leaf shedding, enhances the ability of cassava to survive drought conditions.

Drought also imposes an operational problem in cassava production, since harvesting under drought conditions is extremely difficult.

Rainfall influences the severity and spread of some cassava diseases and pests. The cassava green mite and the cassava mealy bug suffer considerable mortality under rains, so that their intensity of infestation is lower in the rainy season than in the dry season (Yaniek & Animashaun, 1987). Conversely, the cassava bacterial blight is spread by rain-splash, and is more severe in the rainy season.

Cassava thrives best under the full intensity of sunshine. Shading to any appreciable extent results in yield reduction. Photosynthesis in cassava is peculiar in having a combination of C_3 and C_4 characteristics (El-Sharkawy *et al.*, 1989), and there are suggestions that the C_3 pathway operates at lower temperatures, while the C_4 pathway dominates at higher temperatures.

Tuber formation in cassava is under photoperiodic control. Under short-day conditions, tuberisation occurs readily, but when the day-length is greater than 10-12 hours, tuberisation is delayed and subsequent yields are lower (Bolhuis, 1966; Mogilner *et al.*, 1967). Other workers have suggested that tuberisation may be day-neutral (Fukai, 1985). Carbohydrate partitioning in favour of the tuber is favoured by short-day conditions, while flowering is favoured by long-day conditions.

The best soil for cassava cultivation is a light, sandy loam soil of medium fertility. Good drainage is important. On clay or poorly drained soils, root growth is poor, so that the tuber-to-shoot ratio is considerably decreased. Moreover, with the poor soil aeration the few tubers formed tend to rot easily. Gravelly or stony soils tend to hinder root penetration and are therefore unsuitable. Saline soils are also unsuitable. Cassava can grow and yield reasonably well on soils of low fertility where production of most other crops would be uneconomical. Under conditions of very high fertility, cassava tends to produce excessive vegetation at the expense of tuber formation.

2.3 PHENOLOGY OF CASSAVA

Cassava is a perennial plant (Figure 1). In agricultural production, it is propagated almost exclusively from stem cuttings; but in nature and in the process of plant breeding, propagation by seed is quite common. If the cuttings have been planted in moist soil under favourable conditions, they produce sprouts and adventitious roots within a week. The early leaves are small in size, but the size of leaves produced increases progressively until 4-6 months after planting; thereafter, leaf size declines. For propagation carried out by seed, plant establishment is considerably slower. Germination is slow and uncertain, and sometimes it is necessary to scarify the seeds by filing the micropylar end in order to ensure speedy germination. The plant that results from seed propagation is also smaller and weaker than that produced from stem cuttings. The few weeks of the plant's life that follow emergence or sprouting are devoted to expanding the shoot and increasing the depth and spread of the roots. Leaf area approaches a maximum in 4-5 months (Williams and Ghazali, 1969).

Flowering of the plant may commence as early as the sixth week after planting, although the exact time that flowering starts will depend on the cultivar and on the environment. Once begun, flowering will continue intermittently for the rest of the plant's life. Tuber formation has also commenced by the eighth week after planting, as long as the environmental conditions (e.g. photoperiod) are such as will favour tuberisation. The tuberisation process involves essentially the onset of secondary thickening in some of the adventitious roots which were previously fibrous in nature. As the thickening progresses, the roots swell and soon most of the bulk of the root is occupied by fleshy tuber material. Usually, the secondary thickening commences at the proximal part of the root and progresses towards the distal portions. Thus, the tuber is fattest at the proximal part in which the thickening had occurred for a longer time, and it tapers slowly towards the distal portions. For most cultivars, the number of adventitious roots that develop into tubers is limited, and beyond the first 6-9 months after planting, there will be no further addition to the number of tuberous roots (Beck, 1960). After this time, no other adventitious roots change from the fibrous to the tuberous condition.

Cassava is a perennial, although in agriculture it is usually harvested during the first or second year. Abandoned stands of cassava may continue to grow for several years. The plant quite frequently encounters adverse conditions during the period of growth from one season to another. The most common adverse inter-seasonal condition in cassava-growing areas is drought. During dry spells between seasons, the cassava plant reduces or ceases its growth, and sheds a considerable proportion of its older leaves. Increase in tuber size is halted at this time also. When the next rainy (growing) season returns, the plant is able to resume vigorous growth and rapid tuber bulking. Internodes produced during the dry spell are short, while those produced under well-watered conditions are long. As such a cassava plant which has been through several dry spells can be seen to have a series of long internodes alternating with a series of short internodes as one progresses along the stem.

2.4 THE ROOT AND THE TUBER

In cassava grown from cuttings, adventitious roots usually arise from the base of the cutting. Those roots later develop into a fibrous root system which are the main feeder roots of the plant. The roots may penetrate to depths of 50-100 cm (Cours, 1951). Later on, some of these fibrous roots begin to swell and become tuberous. Apparently, all the fibrous roots are initially active in nutrient absorption; but once any of them becomes tuberous, its ability to function in nutrient absorption decreases considerably (Adrian *et al.*, 1969). Only a few (usually less than ten) fibrous roots on each plant ever become tuberous, so that most of the fibrous roots remain thin and continue to function in nutrient absorption.

Cassava grown from seed develops a tap root system. The radicle of the germinating seed grows almost vertically downward and develops into the tap root. Branch roots arise from the tap root, while a few adventitious roots may originate from subterranean stem portions. It seems that the tap root invariably becomes tuberous, and is usually the first root in the plant to do so.

The cassava tuber (Figures 2, 3, & 4) is circular in cross-section. It is generally fattest at the proximal end, and tapers gently towards the distal portion. Unlike the distal portion of the yam tuber, which is blunt and ends abruptly, the distal region of the cassava tuber tapers until its diameter is only about that of a fibrous root. Beyond this, the tuberous root extends for several more centimetres, maintaining a diameter of not more than a few millimetres and being indistinguishable from an ordinary fibrous root. It is as if the tuber proper bears a tail at its distal portion. The tuber is connected to the rest of the plant by a short woody 'neck'.

A mature cassava tuber (excluding the tail) may range in length from 15-100 cm and in weight from 0.5-2.0 kg, depending on variety and growing conditions. The angle and depth of penetration of the tuber, as well as the colour of the tuber surface, are also varietal characteristics, although brown is the predominant tuber surface colour.

In internal structure, the tuber is divisible into three regions (Figure 4). The outermost layer is the periderm, composed mostly of dead cork cells which effectively seal the surface of the tuber. As the tuber continues to increase in diameter, the continuity of the cork layer is broken, so that longitudinal cracks or fissures appear on the surface of the tuber. However, new cork cambium soon forms beneath the cracks and produces cork, thereby restoring the integrity of the protective cork layer. The periderm is only a few layers of cells thick, and as growth progresses, the outermost portions of it are sloughed off, only to be replaced by new cork formation from beneath. Just beneath the periderm is the cortex which is only 1-2 mm thick. It is usually white but may sometimes be pinkish or brownish.

The central portion of the tuber, and constituting the bulk of it, is the flesh. This consists mostly of parenchymatous cells containing large amounts of stored starch. Thin vascular bundles ramify randomly throughout the flesh, and a large strand of vascular tissues runs through the centre of the flesh. Latex tubes (laticifers) occur in the flesh of the tuber, and also in the cortex.

As has already been described, the cassava tuber originates when secondary thickening occurs in a fibrous root that has previously been laid down. As such, tuber growth consists essentially of increase in girth of a root which was previously thin. This means that initial penetration through the soil is accomplished by the relatively thin root, and it is only after this penetration that increase in girth occurs. This contrasts with the mode of tuber formation and growth in yam. In yam, there is no structure that first penetrates the soil before it enlarges to form the tuber. Instead, initial soil penetration is accomplished by the relatively blunt distal tip of the tuber already formed. As such, soil penetration by the yam tuber is expected to be a more difficult process than soil penetration by the cassava tuber. Consequently, the problem of heaving, so common in yam production, is relatively rare in cassava.

While the distribution of roots and tubers in a plant is a varietal characteristic, Onwueme (1977) has shown that it can be influenced by the orientation in which the original stem cutting was planted. In the usual upright planting position, most of the roots form at the extreme basal portion of the cutting, and most of the subsequent tubers are clustered in this position, forming a bunch. A few roots will arise at subterranean nodal positions, away from the basal extremity, and one or two of these roots may also develop into tubers. When the cutting is planted in an inverted position, roots can only arise at the submerged nodes. The tubers that arise later are loosely arranged, and do not form a compact bunch. Some of the other tuber anomalies that accompany inverted plantings will be discussed in a later section. Cuttings that are planted horizontally tend to form roots at nearly all the nodes, and also at the older extremity of the cutting. Tubers produced by such plantings are shallower and more loosely arranged than for upright plantings (Jennings, 1970, Gurnah, 1974).

In comparison to the tubers of yam, sweet potato, or cocoyam, the cassava tuber is physiologically inactive. No eyes or buds are present on it, and none will develop on any part of the tuber even when it is stored for long periods, or planted. As such, the cassava tuber is not used as a means of propagation.

2.5 THE STEM AND LEAVES

The cassava plant grows as a shrub (Figure 1), with the stem reaching heights of up to 4 m in some varieties, or only attaining heights of 1 m or so in some of the dwarf varieties. The colour of the stem surface varies according to the cultivar, but it is usually greyish or brownish. In older parts of the stem, prominent knob-like leaf scars are present, marking the nodal positions where leaves were previously attached. The distance between nodes varies according to the cultivar and also to environmental conditions, being shortest when adverse environmental conditions exist, and longest when growth conditions are favourable.

The internal structure of the cassava stem corresponds to that of a typical dicot stem. In the primary state, before the onset of secondary growth, it is surrounded by an epidermis, beneath which is the cortex. Internal to the cortex are the vascular bundles arranged in a ring. Each bundle consists of phloem and xylem separated by a thin layer of vascular cambium. A prominent pith, composed of parenchymatous cells, occupies the centre of the stem. As secondary growth progresses, the stem increase in girth. Lenticels and cork develop on the surface, and a large amount of xylem (wood) is formed, so that the mature cassava stem is tough and woody.

The pattern of branching of the cassava plant varies with different cultivars. In some, the main stem grows for a while and then produces three branches simultaneously. Each of these branches then grows and later again produces three branches simultaneously, and so on (Jones, 1959). In other cultivars, there is less regularity in the pattern of branching. In any case, the angle of the branches with the main stem determines whether the plant has an erect or spreading form. Another important branching characteristic is how close to the ground the initial branches grow. Cultivars which branch early and very close to the ground may be able to close canopy early, but most of the shoot tends to lie close to or on the ground, so that weeding and harvesting are more difficult. The best type of cassava would be one in which the initial branches are at a reasonable distance from the ground, so that on the field, the crop stand is relatively open beneath the canopy of leaves. Such branching allows room for work between the rows.

The leaves of cassava are spirally arranged on raised nodal portions on the stem. The phyllotaxis is 2/5. Each leaf is subtended by 3-5 stipules, each stipule being about 1 cm long. The leaf petiole varies in length from 5 to 30 cm, but in general, the petiole is longer than the lamina. The lamina itself is simple but deeply palmate. The number of lamina lobes is usually 5-7, although any number from 3-9 may occur. The number of lamina lobes may vary even among different leaves on the same plant. Each lamina lobe is 4-20 cm long and 1-6 cm wide. It is widest at about one-third of the distance from its tip, and from there it tapers towards the base. A mid-rib runs through the centre of each lamina lobe to its tip, but venation within each lobe is reticulate. The edges of the lamina are entire (not serrated), and hairs are usually absent on the lamina surface, except for a few cultivars. In very young leaves, the lamina may be purplish or grey, but in the mature leaf, green is the predominant colour of the lamina. In some cultivars, the mid-rib of each lamina lobe is reddish in colour; in such cases, the petiole is also reddish in colour. Otherwise, both mid-rib and petiole are greenish.

The leaf of cassava is deciduous, and even under the best cultural conditions, each leaf exists for only a few months before it falls off. Consequently, the lower (older) portions of the cassava stem are devoid of leaves, and only the leaf scars indicate the positions that were once occupied by leaves.

2.6 FLOWER, FRUIT, AND SEED

Flowering in cassava is frequent and regular in some cultivars, but in others flowering is rare or non-existent.

Cassava flowers are borne on terminal panicles (Figure 5), with the axis of the branch being continuous with that of the panicle inflorescence. Cassava is monoecious, meaning that the flowers are unisexual with both male and female flowers occurring on he same plant. Indeed each panicle contains male and female flowers. The male ones occur near the tip and the female ones occur closer to the base. The female flowers are usually larger in size than the male ones. Each flower, whether male or female, has five united sepals which may be tinged yellowish or reddish, but there are no petals. The male flower has ten stamens arranged in two whorls of five stamens each. The filaments are free and anthers small. There is an orange-coloured nectar-bearing gland within the flower. The female flower has an ovary mounted on a ten-lobed glandular disc. The ovary has three locules and six ridges and is about 3-4 mm long. Each locule contains a single ovule. The stigma has three lobes which unite to form the single style.

In each inflorescence, the female flowers open first, while the male flowers do not open until about a week later. Cross pollination is therefore the rule. Insects are the main pollinating agents.

After pollination and subsequent fertilization, the cassava ovary develops into the young fruit. It requires 3-5 months after pollination for the fruit to mature. The mature fruit is a capsule, globular in shape, with a diameter of 1-1.5 cm. It has six narrow longitudinal wings. The endocarp is woody, and there are three locules, each containing a single seed. When the fruit is mature and dry, the woody endocarp splits explosively to release and disperse the seeds.

The cassava seed is ellipsoidal and 1-1.5 cm long. It has a brittle testa which is grey, mottled with dark blotches. There is a large caruncle at the micropylar end of the seed. Most earlier reports suggest that germination of the seed requires a long time, and that the duration can be shortened by filing the micropylar end until the white embryo is just visible. However, some experiments (IITA, 1972) indicate that even untreated seeds could give satisfactory germination within three weeks. It was shown that light and severe changes in temperature were not required for germination. The most essential factor was temperature between 30° and 35°C. A wet-heat treatment has also been reported to improve cassava seed germination (Ekandem, 1970).

Chapter 3

CULTIVATION OF CASSAVA

3.1 PLANTING MATERIAL

3.1.1 The rooting of cassava cuttings

When a piece of cassava stem is planted in the upright position (i.e. vertically or at an angle but with the older end of the cutting in the soil), a mass of callus tissue soon forms at the lower cut-end. After a few days, roots can be observed differentiating from the mass of callus, so that within ten days of planting the cutting has already produced roots. A few roots also form at any submerged nodes, but apparently, roots do not normally develop from the internodal regions (Onwueme, 1977). The smooth progression of callus formation and subsequent root formation can only occur if the soil medium remains moist; it is important therefore to avoid desiccation during the first few days after the cutting is planted.

The differentiation of roots from the callus tissue at the base of the cassava cutting is dependent on auxin moving down from the younger to the older portions of the cutting. The buds are mainly responsible for the production of this auxin. If the buds are removed from the stem before it is planted, the number of roots originating from callus is drastically decreased, although the number originating from the nodes is not affected (Indira and Sinha, 1970). It has been possible to increase the number of roots produced by the cassava cutting by applying auxins exogenously. However, since cassava normally roots easily, such applications are not necessary in the normal commercial propagation of cassava.

If the cassava cutting has been planted in the horizontal position, callus will also form at the older extremity of the cutting, and this callus will differentiate to give a large number of roots. In addition, roots will form at each of the nodes, although the intensity of rooting tends to decrease towards the younger part of the stem. If the cutting has been planted in an inverted position with only the younger end in the soil, callus does not form at the submerged extremity of the stem, and roots do not appear.

3.1.2 Length of cutting

Under normal conditions the longer the cassava cutting used for planting, the greater the yield expected from it (Rodriguez and Sanchez de Bustasmante, 1963; F.D.A.R., 1966; Krochmal, 1966; Silva, 1971; Gurnah, 1974). Both the number and the total weight of tubers realized is increased. As a result, cuttings measuring 40-50 cm give a consistently higher yield than those measuring 15-20 cm. The greater yield of the longer cutting is probably due to the greater number of nodes from which roots or shoots can spring. Also the longer cutting contains a greater amount of stored food material which the young plant can utilize before it becomes self-sufficient. Indeed, short cuttings reportedly result in a lower percentage sprouting than long cuttings, and this again contributed to reduced yields per hectare.

Even though long cuttings may yield more than shorter ones, practical considerations have dictated the use of shorter cuttings in many cassava-growing regions. First, the use of long cuttings requires the utilisation of a very large quantity of planting material. In many regions, this requirement cannot easily be met; or it may not be economical if the cuttings have to be transported over long distances. Secondly, long cuttings are unwieldy and cumbersome to handle, especially in mechanical planters. Consequently, most mechanical planters have been designed to utilize cuttings that are 20-30 cm long. Thirdly, if the long cutting is to be planted in the vertical or angled position, the following can occur: so as not to insert the cutting too deep in the soil, a large piece of it protrudes thereby increasing the danger of it falling over. On the other hand if the cutting is to be deeply inserted to avoid falling over, rooting and tuber formation will occur at so great a depth that their growth will be impaired and harvesting will be difficult. Most recommendations for the length of cassava cutting are therefore for cuttings in the 15-30 cm range. Recommendations for Nigeria (20-25 cm), Philippines (25-30 cm), and Sierra Leone (15-25 cm) all fall within this range. In Brazil, the prevailing practice on non-mechanized farms is to use cuttings 50-60 cm long. The mechanized farms utilize 15-20 cm cuttings in the mechanical planters.

It seems that the number of nodes on a cutting may be just as important as the absolute length of the cutting. As has already been mentioned, the nodes are doubly important as origins of shoots and, when underground, also of roots. A cutting with only one or two nodes runs the risk that, if the buds or sprouts from those nodes are destroyed, the stand will fail to establish. In general, it is recommended (Krochmal, 1969) that cuttings used for planting should have at least three nodes, irrespective of the length of the cutting. It is important to follow this recommendation when dealing with cultivars with long internodes. In such cases, even cuttings that may seem normal in length may contain only one or two nodes.

3.1.3 Age of cutting

The age of the stem cutting has a profound influence on the tuber yield. In other words, the part of the stem from which the cutting is taken influences the yield expected from it. Generally, cuttings taken from the older, more mature, parts of the stem give a better yield than those taken from the younger portions (FDAR, 1959; IITA, 1974; Krochmal, 1969; Enyi, 1970). It is, therefore, often recommended that stem-pieces used for planting be as mature as possible. A major restriction on this recommendation is that the basal part of the plant stem is more likely to be infected with mosaic virus (Purseglove, 1968). Where this disease is a problem, use of the oldest stem portion is not recommended. The use of cuttings from tender stem portions is discouraged since such cuttings have great difficulty getting established under field conditions. If, because of scarcity of planting material, such cuttings must be used, then they should first be rooted under ideal conditions in a nursery before being transferred to the field.

3.1.4 Selection and handling of cuttings

In addition to the foregoing considerations, it is important that cuttings should be selected from disease-free plants. As a general rule, cassava stands from which planting material is to be obtained should be cut as close as possible to planting time. The stems are cut near the base of the plant, and stacked or tied into bundles of long stems measuring 1-2 m. It is only just before planting that the stems should be cut to the final length required for insertion into the soil. In most cassava-growing regions, the time interval between procuring the long stems and the actual planting into soil is only two or three days. This situation is ideal, since keeping the bundles of long stems for long periods may result in deterioration as a result of desiccation or rotting. However, in some cassava-growing regions, it is usual to tie the long stems into bundles and store them for some time before the actual planting date. This is partly because some of the bundles of long stems are procured during the harvesting of the previous crop, but will not be planted until the next planting season. In Brazil, bundles are kept in a horizontal position in the open during the cool season. In southern Mexico, bundles of long stems are kept upside down under the shade of trees for up to eight weeks. In Argentina, it is suggested that the stems, cut in autumn, should be piled horizontally in the open, and covered with soil and straw (Sanchez de Bustamante and Rodriguez, 1967). In India, bundles are stacked upright in shade, or in ventilated sheds for up to six weeks. In most of West Africa, protracted storage of the stems is neither practised nor recommended.

3.2 ORIENTATION OF THE CUTTING

There are basically two different orientations in which the cassava cutting is planted in the field. It may be planted *upright* (in a vertical or angled position with part of the cutting sticking out), or it could be planted in a *horizontal* position with the entire cutting submerged beneath the soil.

For plantings in the upright position, the cutting is usually inserted so that about two-thirds of its length is within the soil, while the remaining one-third is exposed. For horizontal plantings, the cutting is inserted horizontally so that the entire cutting lies covered by soil. Depth of insertion is usually about 10 cm, but may vary from 5 to 20 cm.

The orientation of the cutting influences several growth characteristics of the plant. In terms of rapidity of sprouting, upright plantings sprout and acquire appreciable foliage slightly more rapidly than do horizontal plantings (CIAT, 1973). However, the most significant differences occur in the depth and configuration in which the tubers produced are. Upright plantings produce deeper-lying tubers than horizontal plantings. In addition, tubers produced by upright plantings are more compactly arranged than those resulting from horizontal plantings. These findings are not difficult to explain. The upright planting requires that the base of the cutting be inserted relatively deep into the soil. The roots produced at this base are therefore deep-lying and the tubers that develop from these roots are also deep-lying. Indeed the longer the cutting, the deeper the base of it is likely to be inserted into the soil, and therefore the deeper the tubers will lie. The compactness of the tubers results from the fact that most of the tubers from upright plantings arise from the basal tuft of roots. In the horizontal planting, on the other hand, all parts of the cutting lie relatively close to the soil surface, so that the tubers produced are correspondingly close to the surface. Although most of the tubers are produced by the tuft of roots at the older extremity of the cutting, an appreciable number of them arise from the roots produced at each node position. This accounts for the relatively less compact tuber bunch produced from horizontal plantings. In terms of ease of harvesting, the shallow tuber position from horizontal plantings is a definite advantage, although the relative looseness of the tuber bunch tends to detract from this advantage. One further advantage of horizontal plantings is that, because of the superficial position of most of their roots, fertilizers applied from the surface can be utilized more efficiently.

Field experiments comparing yields from upright plantings and horizontal plantings have given very conflicting results. In some, vertical plantings have yielded higher than horizontal ones (Karnjanakorn, 1968). In others, horizontal plantings yielded higher (Takyi, 1974), and, in others still, there were no yield differences between the two (CIAT, 1973; Rodriguez and Sanchez de Bustamante, 1963; Gurnah, 1974). Similarly, Krochmal (1969) reports that in Jamaica, Thailand, and the Virgin Islands, horizontal plantings outyielded upright ones, while in Sri Lanka, vertical plantings yielded more. He offers the plausible explanation that, in regions of high rainfall, horizontal plantings (in which the entire cutting is embedded) may tend to rot and therefore give poor yields. Under relatively arid conditions, upright plantings (with a sizeable portion of the cutting exposed) may tend to dry out and fail to establish. It is advisable, therefore, that horizontal planting should be avoided in regions of very high rainfall or on very heavy soils, while upright planting should not be practised under arid conditions. For regions of moderate rainfall, it appears that cassava could be profitably cultivated with plantings in either orientation.

One further advantage of horizontal planting is an operational one. For upright planting, it is essential that the cuttings be arranged before or during planting so that they can be planted with the correct side up. This requires additional expenditure of time and labour. No such arrangement is necessary when planting horizontally. It is not surprising, therefore, that most mechanical planters in use today are designed to plant horizontally. The machine opens a furrow, the cutting is dropped horizontally, and earth is placed over the cutting.

Some experiments (CIAT, 1973; Onwueme, 1977) have tried to evaluate the performance of cassava cuttings when they are planted in an inverted position, i.e, with the younger part of the cutting in the soil and the older part exposed. This was with a view to ascertaining the necessity or otherwise of expending labour to arrange and orient the cuttings prior to vertical mechanical planting. For inverted cuttings, tubers arise only at submerged nodes, and yield is decreased. Some of the tubers tended to have a bead-like appearance, with thin woody portions separating fat tuberous portions. Also, the bases of the stems of the resulting plants tended to become enlarged and somewhat tuberous. When the inverted cutting was completely submerged but still vertical in orientation, a tuft of roots was produced at the uppermost, morphologically oldest part of the cutting. Most of the tubers arose from this tuft making the tuber bunch very compact, in addition to being shallow lying. Such a tuber disposition might facilitate harvesting, whether mechanical or manual.

3.3 THE SEEDBED

As with most of the tropical tubers, cassava requires a deep, loose, well-drained seedbed. Mounds or ridges are frequently used, but cassava also performs well if planted on the flat. Both planting and harvesting are facilitated if the crop is grown on ridges or mounds.

3.4 SPACING

Cassava is normally planted in rows that are 80-100 cm apart, and the spacing within the row is also 80-100 cm. The exact spacing used depends on the cultivar and on the growing conditions. Cultivars that have a spreading habit should be spaced farther apart than those with an upright habit. Also, in areas of high soil fertility and high rainfall, the plants tend to be very luxuriant in foliage growth, and planting should therefore be spaced farther apart. In all cases it is important that the canopies of adjacent plants merge within the first two or three months of planting. This is helpful in suppressing weeds and in preventing soil wash or soil desiccation.

In traditional agriculture, cassava is rarely grown by itself. When it is, spacing of 80-100 cm between plants is used. More commonly, however, cassava is grown as an intercrop among yams, maize, melons, cowpea etc. In such a case, the distance between cassava plants will depend on the quantity of the other intercrops. Distances of 2-4 m between cassava plants are quite common. It requires some understanding of intercropping and shifting cultivation to appreciate the disadvantage in spacing cassava so widely among the other intercrops. In practice, the cassava is often planted at a time when the other intercrops are almost ready for harvesting. Even if the cassava is planted at the same time as the other crops, it invariably outlasts them in the field because of its long growing season and protracted piece-meal harvesting. Therefore the other intercrops are sooner or later harvested, leaving the cassava as the sole crop in the field. The cassava therefore spends the first part of its field life as an intercrop and the second part as a pure stand. While it is an intercrop, the wide spacing of the cassava does not seem to matter, because the intervening spaces are fully occupied. However, when the other crops are harvested, the cassava is unable to spread across the intervening spaces, so that weeds have an excellent opportunity to take hold. Unfortunately, the farmer is so busy harvesting and processing the other crops that he has little time or inclination to weed the cassava plot. The widely spaced, intercropped cassava is therefore unable to close canopy and is pestered with weeds for the rest of its field life, which may extend a year or more after the other intercrops have been harvested. Yields, of course, suffer. A partial solution to this problem is for the farmer to realize that the cassava will spend a substantial proportion of its time as a pure stand, and therefore that the spacing should be closer. In this case, the cassava should only be planted when the other intercrops are nearly ready for harvest.

3.5 TIME OF PLANTING

Cassava plants are relatively drought-tolerant except during the first few weeks after planting. It is therefore important that cassava should be planted at a time when there is ample soil moisture, and when the likelihood of further moisture supply is good. In regions that have distinct wet and dry seasons, planting should be done as early as possible in the wet season. In this way, the plants are able to have an appreciable growth before the onset of the adverse dry season. Early planting is also useful in the control of the cassava mealy bug and the cassava green mite. It is possible, however, to get reasonable yields from plantings made at any time during the rainy season. In cooler sub-tropical or high-altitude regions, planting should be done early in the warm season to allow for ample growth before the dormant cold season. In traditional agriculture where intercropping is practised, planting is often delayed till the latter part of the rainy season, when the other intercrops are nearly ready for harvest.

3.6 MECHANIZED PLANTING

The planting of cassava has been successfully mechanized in various parts of the world, particularly Brazil and Mexico (Krochmal, 1966). A petrol-driven hand saw is first used to cut the stems to the required size. A multiple-row planter is then used for the actual planting operation. Workers ride on the machine to feed the cuttings, one at a time, into the planting device. The planter opens up a furrow, drops down the cutting horizontally, and then covers it up with a layer of soil. Machines exist which do not require workers to feed the planting device manually, but their use is not widespread.

3.7 WEED CONTROL

Weed competition in cassava is most detrimental to cassava during the early stages of growth before it has formed a closed canopy. In general, a closed canopy does not form until 2-3 months after planting. Once this has occurred, the ground is so effectively shaded that weeds are unable to thrive. The fundamental principle involved in weed control in cassava is, therefore, to keep the plot free of weeds for the first three months after planting. Thereafter, weeds are not a problem and no further weed control is necessary. Indeed, weeding after this time is often discouraged because it may lead to unnecessary damage to the foliage and brittle stems.

The control of weeds during the critical first three months can be done by using hand tools (manual methods), by using herbicides (chemical methods), or by a combination of both chemical and manual methods. Mechanical cultivators could probably be used for effective weed control in cassava, but their use is not wide-spread.

The use of hand tools is the standard method of weed control in cassava plots cultivated by traditional methods. Hoes of various types are commonly used, the Indian hoe being one of the most popular. The machete and cutlass are also in common use. It is important when weeding with hand tools to avoid working the tools too deep into the soil in order not to damage the cassava roots. As with the other tropical tubers, some amount of earthing up is done during the manual weeding operation. When weed control is carried out by manual methods, two weedings are all that are necessary. The first weeding is done 25-30 days after planting, while the second about 60 days after planting (Doll and Piedrahita, 1973). A third weeding at 90 days may sometimes be done, although it is often not necessary. The density of planting often influences weed-control practices. At high plant densities, the canopy closes much earlier, so that the period during which weeding must be carried out is shorter. As such, high yields can be obtained with only one or two hand weedings (CIAT, 1975). When planting density is low and the plants are widely spaced, canopy closure occurs late or not at all, and the necessity for weeding persists. It should be pointed out that, for many traditional farmers who intercrop cassava with other crops, weeding of cassava is only incidental. The farmer's main target is to control weeds in the intercrop, and once he harvests it, no further weeding is done for the sake of the cassava.

For herbicidal weed control in cassava, diuron at 1.6 kg active ingredient per hectare, atrazine (2 kg/ha) or fluometuron (2 kg/ha) have been found to be effective. The herbicide is applied before emergence and can keep the weeds in check for two months or so. Sometimes, a supplementary hoe weeding may be needed after the herbicide effect has worn off in order to keep weeds under control until canopy closure.

3.8 FERTILIZING

When the soil is fertile and growth is normal, cassava removes large amounts of nutrients from the soil. One major consideration in fertilizer recommendations for cassava is that cassava has a high requirement for potassium (Phillips, 1964; CIAT, 1975). Yields on many soils are apparently limited by a lack of adequate potassium. When the potassium level in the soil is low, the response of the crop to nitrogen or phosphorus fertilizers is poor. In the presence of adequate amounts of potassium, the crop is able to respond to moderate (though not high) levels of nitrogen. The increased yield obtained when potassium fertilizer is applied is apparently not accompanied by an increased percentage of protein in the tuber. Instead there is a slight decrease in the protein level so that, even though the total yield per plot has increased, the total protein per plot remains constant. In applying potassium to cassava, it is often best to use potassium sulphate (K_2SO_4) instead of muriate of potash (KCl). The former, but not the latter, is able to meet the additional requirement of the plant for sulphur.

As has already been indicated, an adequate level of potassium is necessary for an appreciable response to nitrogen fertilization. Even then, excessive nitrogen may be disadvantageous for two reasons. Firstly, it results in unusually luxuriant shoot growth, which occurs at the expense of root and tuber growth. As such, the shoot to root ratio is extremely high. Secondly, a high level of nitrogen fertilization results in a high level of cyanogenic glucosides in the tuber (Sinha, 1969; Vijayan *et al.*, 1969; Bruijn, 1971).

It has been reported (Sinha, 1969) that the level of tuber glucoside that results is greater for nitrogen applied to the soil than for nitrogen applied as a foliar spray.

Among the minor elements, cassava is particularly susceptible to zinc deficiency. For this reason, excessive amounts of lime, which can induce zinc deficiency, may result in decreased yields. Cassava roots sometimes form beneficial mycorrhizal associations which may facilitate nutrient absorption.

The high potassium requirement of cassava makes it well suited to traditional agriculture where bush-burning is the rule. The ash left after the bush has been burned is naturally rich in potassium, and cassava planted immediately on such land will benefit immensely. Unfortunately, many traditional farmers do not plant cassava soon after bush-burning. Instead, cassava is reserved as the last crop in the rotation before the farm reverts to bush-fallow. In the meantime, other crops will precede the cassava, which will later be interplanted among them. How much of the initial potash remains for the cassava will depend on the intercrops. Yams, sweet-potato, and cocoyams are all crops that also have a heavy demand for potassium, and would, if they precede cassava, seriously reduce the soil potassium level. In shifting cultivation, cassava planted immediately after bush-burning is therefore more likely to do well than when planted as the last crop before bush-fallow.

Cassava cultivation in traditional agriculture is usually without any form of applied fertilizer. Manures may occasionally be used, but their use is not widespread.

In improved agriculture, cassava is invariably fertilized. However, the precise fertilizer recommendations will depend on the nature of the soil, the previous cropping history of the plot, the cultivar of cassava being grown, the planting density, and several other factors. Generally, a 12-12-18 complete fertilizer is recommended at rates of 450-672 kg/hectare (Kay, 1973). Soils containing less than 0.06% of exchangeable potash should be supplied with 90-120 kg of K_2O per hectare (Ngongi *et al.*, 1976). In Brazil, cassava also responds reasonably well to phosphate fertilizers, sometimes showing more response to phosphate than to potassium or nitrogen (Normanha and Pereira, 1950; Malavolta *et al.*, 1955).

When fertilizer is applied to cassava, it is best to apply it as a band on one or both sides of each plant, so that there is a discontinuous band of fertilizer on one or both sides of the crop row (CIAT, 1975, 1976). Spot placement of fertilizer within, or just beside, the planting hole is also effective. Broadcasting of the fertilizer is strongly discouraged because it is ineffective in supplying nutrients to newly planted cassava, and because it tends to favour weed growth between the cassava stands. Foliar application of fertilizer to cassava stands is occasionally done, but it is most commonly used to supplement, rather than to replace, soil applications.

It is customary to make the major application of fertilizer at the time of planting. This enables the young plants to have a rapid initial growth. If rainfall and leaching have been heavy, a supplementary application of fertilizer may be made about two months after planting. Once canopy closure has occurred, fertilizer application can only be carried out with extreme difficulty; it is therefore not recommended.

The cassava leaf is deciduous, so that as new leaves are formed, old ones are continually being shed. The rate of shedding is even greater under conditions of adverse environment such as drought. It follows, then, that in a cassava stand which is more than a few months old, there is a layer of dropped leaves covering the ground. As these leaves decay, a substantial part of the nutrients which they contain is returned to the soil. For most other crops, a similar process occurs after harvesting when the unharvested portions (stubble) are incorporated into the soil to replenish its fertility. For cassava after harvesting, however, such incorporation is not easy. The stems are relatively woody structures, and decay only very slowly. The rate of decay and ease of incorporation are only slightly improved if the stems are shredded beforehand. It must also be borne in mind that the cassava stem sprouts readily, and many of the pieces that are incorporated into the soil will emerge later as weeds in subsequent crops. The use of cassava stubble to replenish the fertility of the soil is therefore limited.

Korchmal and Samuels (1968) give descriptions of several deficiency symptoms in cassava. They have also indicated that leaf analysis is unsuitable for detection of mineral deficiencies in cassava. Cours *et al.*, (1959), on the other hand, concluded that the phelloderm of the principal stem is the best organ for diagnosis of the nutrient status of cassava.

3.9 YIELDS

Yields that can be realized from cassava cultivation vary considerably, depending on such factors as the cultivar used, cultural operations, fertilizer levels, type of soil, field spacing, and type of climate. Some of these factors have already been discussed. On a world basis, the average yield is estimated to be about 10 tonnes/hectare (FAO, 1991). Yields in South America and Asia average over 12 tonnes/hectare, while those in Africa are about 8 tonnes/hectare.

The components that contribute to yield are the mean weight per tuber, the number of tubers per plant, and the number of plants per hectare. Since starch is the predominant utilizable component of the tuber, the percentage starch content of the tuber may also be listed as one of the yield components. This percentage is influenced by the cultivar, as well as by the age of the plant at harvest. The starch content is low at first, then increases, reaching 25-30% at 9-15 months. In some cultivars, the starch content may decrease thereafter, but, in most of them, it will continue to increase up to 30-35%. However, the tuber becomes increasingly fibrous and woody, making it difficult to process. The yield of extractable starch therefore declines. It is best to harvest when the starch content first reaches 25-30%.

The mean weight per tuber shows an increasing trend almost throughout the life of the plant. It is only during and immediately following periods of adverse weather (e.g. drought) that the mean weight of each tuber may remain constant or decrease. In this context, it should be pointed out that, even though a cassava plant may have been in the field for 18-24 months, the period during which it has had a fruitful growth may be considerably less. Cassava may remain in the field during the dry season, but additions to tuber material during that time are probably negligible. The total weight of tubers at harvest should, therefore, be related, not to the number of months since planting, but to the number of months during which vigorous growth has occurred. A nine-month old cassava plot that has experienced no drought may give as good a yield as a twelve-month old plot that has been through a three-month dry season.

Different tubers on the plant may vary greatly in weight. The number of tubers per plant usually varies from four to ten. The number is dependent on cultivar as well as on orientation of the cuttings. Horizontally planted cuttings tend to have more tubers per plant. The number of plants grown per hectare is influenced by weed-control considerations, as has already been discussed. Since the planting material costs very little, it is safer to have more than the optimum number of stands per hectare, rather than fewer.

The number of stems per plant does not affect cassava yield (IITA, 1974, 1975). Plants with only one or two stems tend to branch more profusely, thereby compensating for the scarcity of stems. The same situation probably occurs when interplant spacing is very wide. The pruning or defoliation of cassava plants, for whatever reason, reduces tuber yields considerably. It should therefore be discouraged, except in situations where the leaves must be harvested for consumption.

3.10 CROPPING SYSTEMS FOR PRODUCING CASSAVA

There are several characteristics of cassava and its delivery system which determine or affect the cropping systems used throughout the world:

a) Its fertility requirement is lower than that of many other tropical field crops. It can grow and yield reasonably well under low fertility conditions.

b) It is relatively drought tolerant, and therefore able to grow in some areas where other crops may fail due to aridity. The drought-tolerant characteristic also means that it can be planted later in the rainy season and allowed to remain on the field through the dry season.

c) The plant habit is a shrub which attains heights of one to two metres. Therefore in intercropping systems, it has the ability to shade recumbent or low lying crops (such as melon, cowpea, soyabean, sweet potato, groundnut), and may in turn be shaded by tree crops and other tall species.

d) The crop is mostly grown for subsistence and often left to "store" in the ground until needed, aided by the botanically perennial nature of the cassava plant. Therefore agronomic field occupancy is long (over one year) and indefinite. This has implications for the kinds of cropping systems into which it is incorporated.

e) The main subsistence nature of the crop means that on a world wide basis average holdings are no more than one or two hectares each.

Probably because so much of it is used for subsistence, a very high proportion (up to half) of cassava produced in the world is raised under intercropping. The dynamics of cassava growth is such that there is ample space available in the field (above and below ground) during the first three months after planting, when canopy and root elaboration are still occurring. A quickly maturing annual could therefore be profitably grown up to about the fourth month after planting without much adverse effects on cassava yields. Conversely, cassava could be planted in relay intercropping into some other crop that has two to three months left to mature. After canopy closure in about the fourth month for normally-spaced cassava, total light interception by the plant remains high until about the ninth month after planting (Leihner, 1983). Thereafter, light interception decreases somewhat; but introducing an intercrop at this time is complicated by the high canopy of the cassava, the prospect of its imminent harvest, and possible onset of the dry season. Of course, cassava could always be spaced wider to permit intercrops to be planted at virtually any stage of the cassava cycle. In such cases, however, cassava yield per hectare is invariably compromised.

Various practices exist in different parts of the world with respect to cassava intercropping. In Africa, where most of the world cassava is grown, over half of it is grown under intercropping. Most frequently, relay intercropping is used, but because of its ability to tolerate reduced fertility, and the need for it to stand on the field indefinitely, cassava is often the last crop in the relay . Shifting cultivation is also a common feature of these systems, so that cassava is the last crop before the land is allowed to revert to bush fallow. In southern Nigeria for example, a typical cycle in the traditional cropping system would be to start with maize/melon, into which yam is planted a month later. After four months cassava is planted between the yams, utilizing the space vacated by the melon and maize which have been harvested. Yam harvesting occurs two to three months after the cassava is planted, so that cassava remains effectively as a sole crop through the dry season and into the next growing season, when it might be harvested. Intercropping systems involving cassava, maize and cowpea are also common in Nigeria. In Liberia and Sierra Leone, cassava is an important component of the rice-based intercropping systems. Intercrop mixtures involving rice, cassava, maize and fruit vegetables are quite common. In Zaire, cassava is often intercropped with millet, groundnut, melon, and sesame.

In South and Central America, intercropping may account for up to forty percent of cassava production. In Colombia and Brazil, it is often intercropped with maize and pulses, while yams are sometimes included as an intercrop with cassava in Nicaragua and Colombia. Cassava is also frequently used in plantation cropping systems, as an intercrop in young plantations of cocoa in Costa Rica, oil palm in Colombia, and rubber in Brazil. However, cassava yield under plantation tree crops is usually quite low.

In Asia, cassava grown for subsistence is also quite commonly intercropped. In Malaysia, cassava is often intercropped with maize and groundnuts, or planted between young trees of rubber or oil palm in plantations. Growing cassava between coconut trees is practised in the Philippines, India, Thailand, and Malaysia. In Indonesia, the rice-based cropping systems often grow cassava on elevated beds surrounding low lying strips where rice is grown.

Sole cropping of cassava is extensively practised world wide, particularly in places such as Thailand, where the crop is essentially a cash crop. In such situations, sole cropping permits a higher level of technology (fertilizers, pesticides, mechanization) to be introduced into the production of the crop. In the future, experimentation with alley cropping and with early maturing cassava may have profound effects on cropping systems for cassava production.

Chapter 4

DISEASES AND PESTS OF CASSAVA

4.1 CASSAVA MEALY BUG

The cassava mealy bug (*Phenacoccus manihoti*) is native to South America. It was introduced into Africa in the early 1970s, being first reported in Zaire. Since then it has spread rapidly to nearly all the cassava growing regions on the continent. Infestation with the mealy bug results in stunted growth, shortened internodes, and leaf drop. The shoot apex necrosis, dies back, and is covered by the white mass of the mealy bug, thus giving it a candlestick appearance. Damage by the pest is most serious during the dry season, and in cases of severe infestation, yield losses up to 75% can occur.

Initially, efforts to control cassava mealy bugs by means of pesticides proved ineffective, since they have a waxy covering that effectively shields them from most pesticides. The main control measure used by farmers is to plant early, to enable the crop to attain an advanced stage before the dry season when mealy bug infestation is most likely to be severe. In 1981 biological control was introduced in Africa using the South American parasitic wasp, *Epidinocarsis lopezi*. After screening and evaluation, the wasps are released in cassava fields. The effectiveness of this control measure has led to its widespread use in controlling the mealy bug in over thirteen countries in Africa, including Ghana, Togo, Zaire, Congo and Benin (Neuenschwander *et al*., 1987). Cassava clones resistant to cassava mealy bug are also available e.g TMS 4(2)1425, TMS 91934 and TMS 70453. The clone TMS 70453 appears to resist cassava mealy bug by antibiosis. There are indications that shoot pubescence may contribute positively to cassava tolerance to the cassava mealy bug (Kanno *et al*., 1991).

4.2 CASSAVA GREEN MITE

The cassava green mite (*Mononychellus tanajoa*), like the cassava mealy bug, is also native to South America and was introduced to Africa in the early 1970s. It is a pest in both the African and South American cassava producing regions. The mites occur on the buds, leaves, and apical stem portions of infested plants. Leaf deformation and leaf drop may occur. In severe infestations, yield losses may be as high as 30%. The cassava green mite is also most severe in the dry season; early planting is one of the control measures used. Biological control measures are being developed, and resistance based partly on pubescence is also being explored. Cultivars that have shown some degree of resistance include TMS 4(2)1425 and TMS 91934. Leaf pubescence in some cultivars seems to be associated with reduced green mite infestation.

4.3 CASSAVA MOSAIC VIRUS DISEASE

The cassava mosaic virus disease, also called the African cassava mosaic disease, is prevalent in all cassava producing areas of Africa, with some incidence reported in India and Indonesia. The disease is relatively rare in South America. Symptoms of the disease include a whitish or yellowish chlorosis of the young leaves, accompanied by leaf distortion and reduction in leaf size. The growth of the entire plant is stunted, and normal increase in tuber weight is disturbed, so that yield is significantly reduced. The percentage starch content of the tubers is also reduced and in some instance there may be continuous longitudinal splits as well as malformation of the tuber (Narasimhan and Arjunan, 1973).

At the cellular level several symptoms have also been ascribed to the cassava mosaic disease. Leaves of infected plants have fewer and smaller chloroplasts, and the content of chlorophyll, carbohydrate, sugars and starch are lower (Alagianagalingam and Ramakrishnan, 1970). The photosynthetic rate is decreased, and there is increased activity of chlorophyllase enzyme in the leaves and amylase in the tubers. There is a decrease in total lipids, phospholipids, and triglycerides in the leaves and petioles (Ninan *et al.*, 1976). In addition there is a decrease in the amount of laticifers in the infected leaf portions (Murant *et al.*, 1973).

The cassava mosaic disease virus is spread by the white fly, *Bemisia tabaci.* When the fly carrying the virus feeds on a healthy cassava plant, it transmits the virus, and the disease symptoms soon develop. The disease is also transmitted when cuttings from infested stem portions are used for propagation. Indeed the disease symptoms are more severe, and the yield reductions greater, if the disease was present in the cutting used for planting rather than if it was transmitted by the white fly after the plant was established. The castor plant (*Ricinus communis*) and the wild cassava (*Manihot glaziovii*) may act as alternative hosts to the cassava mosaic virus (Singh, 1973).

By far the most effective control measure for the disease is the use of resistant varieties. Several such varieties are currently available, for example TMS 30555, TMS 30572, and TMS 63397. The basis of resistance in some cultivars is that after infection the virus moves rapidly down the plant and is restricted to the basal portions of the stem. In other cultivars, it seem that the fecundity of the white fly vector may be significantly reduced (Singh, 1973).

A second control for the African cassava mosaic disease lies in careful selection of planting material. Furthermore, some amount of control may be achieved by attempts to inactivate the virus by means of heat treatment. When infected cuttings are grown at temperatures of 35-39°C for 4-6 weeks, the virus is inactivated and new shoots appearing are devoid of symptoms of the disease (Chant, 1959). This control measure is difficult to apply on a large scale basis. Finally attempts have been made to control the disease by controlling the white fly vector. Insecticidal sprays during the first six months after planting can keep the whitefly population low and reduce the severity of the disease.

4.4 CASSAVA BACTERIAL BLIGHT

The cassava bacterial blight was for decades a serious disease in South America. It was later introduced into Africa. It has also been reported in several countries in Asia such as Thailand, Malaysia and Taiwan.

The symptoms of the disease appear on the leaves as angular spots, blights, and wilting (Lozano and Booth, 1973). There is vascular necrosis of the stem and roots, gum exudation and die back of the shoots. If the infection is present in the planting material, then the young sprouts produce wilt and die back. If infection occurs after the plant has been established, then angular leaf spotting, blight, defoliation, and eventually die back follow. The leaf spots first appear on the under-surface of the leaves. They enlarge, coalesce, and form large necrotic areas, so that eventually the leaf rolls up and dies. Gum exudation occurs from the under surface of spotted leaves, as well as from cracks that develop on infected young stems and petioles. Young sprouts die back; then new sprouts arise from the more basal portions. These in turn die back. Thus there is a series of successive sprouts that die back. Older stem portions may appear symptomless but still contain the bacteria. Symptoms in the tuber are usually slight and are limited to necrosis of the vascular strands.

Cassava bacterial blight is caused by the bacterium *Xanthomonas manihotis*. It penetrates the host through stomata or through small surface wounds. Once in the host, it destroys the spongy mesophyll of the leaf and enters the foliar vascular tissues. It then spreads systemically to the vascular tissues in all parts of the plant. Most of this movement occurs in the xylem vessels. Once infection and vascular invasion have occurred, visible symptoms appear within two weeks. The disease is disseminated from one location to another and from one season to the next by the use of infected cuttings. On a localized field basis, splashing of rain is the most important means of spreading the infection from diseased to healthy plants. Insects may also play a significant role by mechanically transferring the bacteria from plant to plant. The bacterial cells can only survive for a few weeks in soil, and if the soil is dry or flooded, their survival time is reduced to one or two weeks. In dead plant tissue, however, the bacteria can survive for over four months (CIAT 1975, 1976).

Fortunately there are several resistant cultivars available for the control of cassava bacterial blight. These include TMS 63397, TMS 30555 and many others. Most of these have been released from the International Institute of Tropical Agriculture (IITA) and have the added advantage of also being resistant to the African cassava mosaic disease. In some of them, resistance to the cassava bacterial blight is assocaited with limiting the penetration of the bacteria, and systemic invasion, or evoking a hypersensitive response by the host.

A second control measure for the disease is the use of disease-free planting material. Sprouts arising from older portions of infected plants are usually free of the disease for the first two or three weeks after they appear. Such young disease-free sprouts can then be excised and rooted to produce healthy plants. This is a useful device for providing certified bacteria-free planting material from a clone that is already infected. The use of meristem tissue culture can achieve this purpose more effectively if the facilities are available. A third control measure is the effective management of diseased material. If the diseased plant residue is burned just before the onset of the dry season, then the bacteria will be effectively controlled, since they cannot survive in dry soil. Quarantine measures to reduce international and inter-regional movement of diseased material are also helpful. Effective crop rotation is a fourth measure for controlling the disease. The bacteria causing the blight are mainly limited to the genus *Manihot,* and only survive in the soil for a few weeks. Therefore, if other non-susceptible crops are grown for one or two seasons before returning to cassava, the disease would be effectively controlled.

4.5 OTHER DISEASES AND PESTS

Other important diseases of cassava include:

a) **Cassava anthracnose** disease which causes wilting and death of young stems and leaves after sunken spots appear on them. Control is by the use of resistant varieties such as TMS 4(2)1425 and TMS 63397.

b) Brown leaf spot which causes large brown irregular necrotic spots which appear on older leaves. The disease has been reported in South America, Asia and Africa. Control is by use of resistant varieties (e.g. M Mexico 59) or by the use of cuprous oxide sprays.

c) The variegated grasshopper (*Zonocerus* species) which does considerable damage to cassava through its feeding activities. Infestation is most severe during the dry season and early in the rainy season. The grasshopper does not attack cassava until its nymph has reached the fourth instar. The insect also appears to prefer some cultivars over others, so that a basis for limited resistance already exists.

d) Mammals, particularly rodents and wild pigs, may attain local importance as pests of cassava. They feed on the cassava roots while the plants are growing. They not only reduce yield but also help to spread various tuber rots. Control is by entrapment, fencing and the use of poison baits.

Chapter 5

HARVESTING, STORAGE AND UTILIZATION OF CASSAVA

5.1 HARVESTING

As previously mentioned, tuber formation in cassava commences by the end of the second month after planting. With time, the tuber continues to increase in size, due to the deposit of large amounts of starch within the tuber tissues. It follows, therefore, that very young tubers contain much less starch than older tubers, so that harvesting must be delayed until an appreciable amount of starch has accumulated. However, as the tuber becomes older, it becomes more lignified and fibrous, so that the starch content, as a percentage of the total dry weight of the tuber, tends to decrease or remain constant. It is therefore best to harvest cassava at a time when the starch content of the tubers is at its maximum. For most cultivars, this occurs 12-18 months after planting, although some recently released early-maturing cultivars are ready for harvest in 8-9 months.

In practice, cassava plots are hardly ever harvested all at once, or all at the recommended time of harvesting. This is invariably true in traditional agriculture, and is also often the case even in improved agriculture. The main reason for this practice is that the cassava tuber, once harvested, deteriorates rapidly. Therefore, the farmer prudently harvests only what he needs for the moment, leaving the remaining tubers unharvested until needed. The plot is therefore harvested in aliquots, and in cases where the plot is being harvested for household use, harvesting on a particular plot may be spread over a period of up to a year. In general, farmers leave the tubers in the ground to extend the storage life. This practice is made possible only by the fact that the cassava plant is a perennial. The plant continues to live and maintain itself even though the tubers might be well past their maturity stage for harvesting. Such a practice, for example, would be unthinkable for yam where the plant dies soon after the tuber is mature. The death of the plant means that no further increase in tuber material can occur, and that the tuber itself is more prone to deterioration.

Cassava may be harvested manually or by machines. Hand harvesting is the rule in traditional agriculture and is employed to some extent in improved agriculture, on plantations where mechanical harvesting has not been introduced. In hand harvesting, a machete is used to cut off the stem a few centimetres from the ground. Then a tool is used to loosen the ground around the tubers. When the ground is sufficiently loosened, a pull at the remaining stub of stem is enough to lift out the tubers. The rapidity with which harvesting can be done by this method depends very much on the compactness of the soil. On compact soil, a man may be able to harvest only 500 kg/day, while on loose soils he may harvest up to 1000 kg/day. In this context, harvesting during the dry season, when the soil is compact, is more difficult than harvesting during the rainy season. Wherever possible, therefore, it is advisable that most of the harvesting be carried out during the rainy season. Sometimes it is more economical for some cassava-processing factories to close down during the dry season rather than cope with the extra expense of harvesting. This problem would be solved if and when effective methods of storing the fresh cassava tuber are devised. Tubers could then be harvested in bulk during the rainy season and stored for use during the dry season.

Two other cassava-harvesting practices which are occasionally encountered in traditional agriculture should be mentioned here. The first is the practice of replanting the field as it is harvested. Once the tubers of a plant have been lifted, a piece of stem from that plant is planted in the same hole or very close by. In this way, by the time the entire field has been harvested, the entire field has again been replanted, although the plants will be at different ages. Harvesting of the second crop, when due, will of course begin from the older plantings, so that the plants are all harvested at approximately the same age. This practice of planting while harvesting has the sole advantage of saving labour. Since cassava follows cassava in rotation yields of the second and subsequent cassava crops decrease. Even in traditional agriculture, this practice should not be encouraged. Fortunately, it is not very widespread. Still less widespread is the second practice, which involves harvesting only portions of each plant, leaving the plant to form new tubers before it is harvested again.

The mechanical harvesting of cassava has met with some success in Brazil and Mexico, and is being vigorously developed in other parts of the world. The first operation in mechanical harvesting is the removal of the tops of the plants. This is accomplished by mounting a heavy screen in front of a tractor. The screen pushes down the tops, while a rotary mower behind the tractor cuts them down. Alternatively, a rotary saw or hedge trimmer mounted in front of a tractor and powered by a separate engine could be used (Bates, 1963). The tops that are removed may be shredded mechanically for subsequent incorporation into the soil (Silvestre, 1989). They may also be left in windrows, or even carted away to serve as a source of planting material. Once the tops have been cut, the recovery of the tubers must be done within a few days; otherwise the plants will begin to utilize tuber reserves in an attempt to produce new shoot growth, and the tuber yield will continue to decrease. All the same, it is advisable not to attempt to lift the tubers on the day the tops are removed; a delay of one or two days allows the tops to wilt and makes them easier to handle during the lifting operation.

Several types of lifting devices have been tried, but none has been found to be completely satisfactory. Bates (1963) reported that neither the potato spinner nor the potato lifter-digger was suitable. Makanjuola *et al.* (1973) tried to lift cassava roots using a mould-board ridger, a mould-board plough, or a mould-board plough with the board removed, and were able to expose 75, 81 and 83% of the roots, respectively, for subsequent hand-picking. Other cassava harvesters have a shear in front for slicing the earth and lifting, while a vibrating device at the rear separates the tubers from the soil.

5.2 UTILIZATION

5.2.1 Composition of the cassava tuber

The tuber consists of the peel and the flesh. The peel comprises 10-20% of the tuber. Of this, the cork layer represents 0.5-2.0% of the total tuber weight. The edible fleshy portion constitutes 80-90% of the tuber. The tuber flesh is composed of about 62% water, 35% carbohydrate, 0.5-1.5% protein, 0.3% fat, 1-2% fibre, and 1% mineral matter (Table 4). Most of the carbohydrate fraction is starch, which makes up 20-25% of the tuber flesh (Purseglove, 1968). Among the minerals in the tuber, phosphorus and iron predominate; there is a small amount of calcium. It is relatively rich in Vitamin C (35 mg per 100 g fresh weight), and contains traces of Niacin and Vitamins A, B_1, and B_2, but the amounts of thiamine and riboflavin are negligible.

The protein of the cassava tuber is rich in arginine, but low in methionine, lysine, tryptophan, phenylalanine, and tyrosine (Oyenuga, 1968). As such, the protein is not only low in quantity, but it is also poor in quality. It seems that there is a relatively large amount of non-protein nitrogen in the tuber, so that protein contents estimated from nitrogen analysis tend to be higher than those estimated from amino-acids (Martin and Splittstoesser, 1975). The peel of cassava is much richer in proteins, ether extract, and ash than the flesh.

5.2.2 Cyanide in cassava.

Virtually all parts of the cassava plant contain small but significant quantities of cyanide or cyanogenic compounds. The cyanide in cassava exists roughly as two types:

a) the *free cyanide* made up mainly of cyanohydrins, small amounts of HCN (gaseous above 26°C), and CN^- ion (under alkaline conditions).

b) the *bound cyanide* existing as two cyanogenic glucosides, namely linamarin and lotaustralin.

Both the free cyanide and the cyanogenic compounds are collectively referred to here as "cyanide" in view of the fact that:

i) on hydrolysis they all yield cyanide

ii) they exert their harmful effects mainly through their ability to produce cyanide

iii) they are usually assayed by hydrolysis, followed by quantification of the cyanide produced.

About one-quarter to one-third of the total cyanide is present as free cyanide, while the rest is bound cyanide. Of the bound cyanide, linamarin constitutes about 93%, while lotaustralin is approx. 7% (Bradbury and Holloway 1988). Linamarin is synthesized in the leaves from the amino-acid valine, while lotaustralin is synthesized from the amino-acid isoleucine. From the leaves, the glucosides are translocated to other parts of the plant. At the cellular level, they are stored in the vacuoles; but the concentration stored varies considerably from tissue to tissue. In the cassava tuber, the concentration of cyanide ranges from 1-100 mg/100g fresh weight, but the range of concentration is a varietal characteristic. Some cultivars are characterized by low cyanide (sometimes erroneously called "sweet" cultivars) while others have high cyanide (erroneously called "bitter" cultivars). For all types, cyanide content is usually higher in the peel of the tuber than in the flesh, but in the high cyanide types this difference is less pronounced than in the low cyanide types.

Within each cultivar, there are some factors which may influence the cyanide level: plant age is one. As the plant gets older, the cyanide in the tuber increases, attains a peak, and then declines (Sinha & Nair, 1968). Plants growing on soils low in potassium or high in nitrogen also tend to have a higher cyanide content.

The cyanogenic glucosides are soluble in water, and tend to decompose if heated up to 150°C. They can be hydrolysed at ambient temperatures under the influence of the enzyme linamarase, to produce the corresponding cyanohydrins. The resulting cyanohydrins as well as those normally present in the tissue, in turn breakdown to give HCN and ketones. This breakdown is spontaneous at pH above 5.0, but in acid medium is catalysed by a hydroxy-nitrile lyase. Either way, the resulting HCN is lethal for humans (oral lethal dose is 0.5 to 3.5 milligram per kilogram body weight). Therein lies the danger of cyanide in cassava.

In the intact plant tissue, linamarase occurs in the cell wall, and is physically separated from the glucosides, which occur in the vacuole. It is only when cassava tissue is crushed that linamarase is able to come in contact with the glucosides and hydrolyse them. The resulting cyanohydrins and HCN can be removed by heating, and this forms one of the most important methods of detoxifying high cyanide cassava. In general, the following methods are utilized for reducing the cyanide level of cassava before consumption:

i) Crushing, maceration or pulverization to bring linamarase in contact with the glucosides, followed by removal of the resulting HCN by squeezing out the juice and heating. The leaves contain a much higher concentration of linamarase (up to 100 hundred times higher) than the tuber, so that this process alone may result in almost complete hydrolysis and cyanide removal from cassava leaves that are destined for human consumption. e.g. in making *pondu* in West Africa.

ii) Decomposing the glucosides directly by heating them above 150°C.

iii) Sun/oven drying which removes about 80% of the free cyanide and 80-90% of the bound cyanide.

iv) Retting i.e. prolonged soaking in water of the tuber. Apparently fermentation micro-organisms attack the tuber during retting, making it more permeable. This permits the glucosides, which are water soluble, to leach out from the tuber into the water. The micro-organisms and linamarase may also directly hydrolyse the glucosides during retting. However, retting results in an acid solution which makes further breakdown of cyanohydrins difficult. In any case, retting followed by sun drying can remove up to 99% of the cyanide.

No matter how carefully cassava has been processed, traces of cyanide invariably remain in the consumed product. For persons heavily dependent on cassava diets, the total quantity of cyanide ingested can be appreciable. Ingested cyanide is metabolized in the human body by its reacting with sulphanes to produce thiocyanates. The sulphur for the sulphanes comes from methionine and cystine, two essential amino-acids. Ironically, the detoxification of cyanides to produce thiocyanate is not without cost to the body physiology. Not only is it a drain on sulphur-containing amino acids, but high amounts of thiocyanate are known to inhibit the accumulation of iodine in the thyroid gland, resulting eventually in iodine deficiency, endemic goitre, endemic cretinism, and mental retardation. Thus the danger of high cyanide in cassava is not only in the risk of sudden death when lethal doses are eaten, but also in the more insidious risk of endemic diseases resulting from long term ingestion of sublethal doses.

The easiest way to reduce the cyanide problem in the cassava delivery system is of course to encourage the farmers to change over to low cyanide cultivars. However, there has been much controversy in recent years over the need or otherwise to encourage this change over. Some argue that the high cyanide content offers the crop some protection against diseases and pests, and that there may even by a genetic link between high cyanide content and high yields. Others argue simply that the risk and processing inconveniences imposed by the high cyanide far outweigh any advantages derivable from them. With modern tools of plant breeding and bio-technology, it should be quite possible to incorporate into low cyanide cultivars, any crop protection or yield advantages that the high cyanide cultivars may have.

5.2.3 **Utilization of the fresh tuber**

Two major factors tend to limit the direct utilization of cassava in the form of the fresh (unprocessed) tuber. The first, already discussed, is that the unprocessed tuber has relatively high amounts of cyanide. The second factor is that the fresh cassava tuber, unlike yam and the other tropical tubers, cannot be stored for more than a few days after harvesting. A day or two after it is harvested, the tuber begins to deteriorate rapidly. The primary deterioration involves bluish discolouration of the vascular bundles of the tuber, a symptom sometimes referred to as *vascular streaking* (Averre, 1967). Streaking is caused by enzymatic processes, including the production of catechin and coumarin. It fails to occur if the tubers have been dipped in warm water (53°C for 45 minutes), stored under anaerobic conditions, submerged in water, or kept under refrigeration. Secondary deterioration may involve microbial rotting following vascular streaking. In addition to vascular streaking, the quality of the starch in the tubers also deteriorates during storage. It has, however, been possible to store fresh cassava roots for up to eight weeks in boxes containing moist sawdust (CIAT, 1974) or in clamps. The storage is preceded by the curing of the tubers at 30-35°C and 80-85% relative humidity. This type of storage is probably economical when handling small quantities of tubers that will be used as fresh vegetables; but it will probably not suffice if the intent is to store large amounts of tubers while they await processing or consumption.

The high cyanide content of most cassava cultivars implies that they can only be consumed after elaborate processing. Only tubers of cultivars with very low cyanide content can be safely consumed with little or no processing. Such tubers may be eaten raw as a salad or snack, or they may be boiled, or roasted. Alternatively, they may be boiled, then pounded into a paste resembling pounded yam, and eaten with a sauce. *Fufu* in Ghana is prepared in this way.

The fresh cassava tuber also finds considerable use as feed for livestock. Sheep, goats, cattle, and particularly pigs are often fed on fresh cassava tubers, which they find palatable. In such feeding, supplements of proteins, minerals, and vitamins should be provided, and the cassava should not be more than 40% of the dry-matter content of the ration. Sometimes cooked cassava tubers are used instead of the raw ones. In many rural households, cassava peel is fed to domestic animals instead of being discarded.

The major processed forms of the cassava tuber fall into four general categories: **meal, flour, chips, and starch.** Meal forms include *gari, farinha*, and meal of retted cassava. The meal and flour forms account for the bulk of cassava used for human food in the tropics. Cassava chips, and cassava starch are mainly industrial products that are little used for direct human consumption, but they account for most of the cassava that enters into international trade.

5.2.4 Toasted cassava meal: *gari*, *farinha*, etc.

Gari is by far the most popular form in which cassava is consumed in West Africa. It accounts for about 70% of cassava consumption in Nigeria, 40-50% in Cameroon, 40% in Ghana, 30% in Côte d'Ivoire, and 60% in West Africa taken as a whole (Dorosh, 1988). For its preparation, the harvested cassava roots are peeled, washed, and then grated or crushed. The juice is extracted from the crushed meal by subjecting it to heavy pressure for 2-4 days. A slight amount of fermentation occurs during this period. At the end of the period, the meal is removed from the bags, and sieved. The sieved material is then placed, a small amount at a time, in wide, shallow, metal pans over a fire, and toasted ("fried"). Constant stirring is carried out during the toasting. A small amount of oil may be added to the meal while it is in the pan to prevent burning and improve the colour. When the meal is sufficiently dry, it is removed from the pan, and spread out in a secluded place to complete the drying, and cool down. The product at this stage is ready for consumption, although it is sometimes sieved again to produce *gari* of various particle sizes. The production of *gari* therefore involves the following distinct steps: peeling, grating/crushing, pressing, sieving, toasting, and separation into various particle sizes. The crushing of the tuber enhances contact between linamarase enzyme and the cyanogenic glucosides, so that most of the glucoside can be hydrolysed to free cyanide. The pressing stage serves to extract the juice containing free cyanide, while the toasting stage vaporizes most of the remaining cyanide. Detoxification of the cassava therefore proceeds to an appreciable extent. The final *gari* produced usually contains 20-30 mg of cyanide per kg of *gari* . Since each kilogram of *gari* results from about 2 kg of fresh roots containing up to 800 mg of cyanide, it can be seen that substantial reduction in the cyanide content has occurred.

The technology used for *gari* production has evolved considerably over the last few decades. Peeling is still done by hand in most places although motorized peelers have been developed. Grating was originally carried out by rubbing the tuber-piece repeatedly over a flat metal sheet that had been roughened by numerous nail-punches, but today motor-driven mechanical crushers are available in most rural communities. Some of these are fixed at central locations in the community, while others can be moved from house to house. Pressing is sometimes still done by tying the bags of meal tightly between wooden poles and placing stones and other heavy weights on them. However, manually operated hydraulic presses are also in common use for this purpose. Sieving is done manually on a flat sifter woven out of palm fibre or similar material; however mechanical sievers are also available. Toasting is done over wood-fires, or occasionally coal, oil or gas fires. The operator sits besides the pan on the fire, constantly turning the meal with a ladle or a piece of calabash material. Effort is also made to prevent the meal from forming lumps, and the operator intermittently beats lumpy sections of the meal to disintegrate them. The separation of the final product into various particle sizes is rare in traditional *gari* manufacture.

Even though much mechanization has been introduced in *gari* production at the village level, the toasting process is still a major bottleneck. It is physically tedious and also harmful, since the operator is subjected to heat and cyanide fumes for hours on end. The toasting stage has been mechanized, and various types of "gari-frying machines" are available on the market. What is needed is an effective extension of the technology, so that village-level producers of *gari* can have access to advanced "frying" technology, even on a pay-for-use basis. Onwueme (1981) has proposed a cassava delivery system that can accomplish a similar purpose.

Considerable mechanization has been introduced into *gari* manufacture at the industrial level. Several integrated factories for *gari* manufacture have sprung up (Purcel and Williams, 1973: Wadhwa, 1973). The cassava coming in from the field is weighed, washed, peeled, grated, pressed, sieved, toasted, and re-sieved with a minimum involvement of manual operations. In the final re-sieving, the *gari* is separated into chaffy, fine, coarse, and medium size fractions. The use of a hydraulic press for the pressing stage of *gari* manufacture means that all the juice in the meal can be extracted in a matter of minutes. There has therefore been a tendency to shorten pressing time in mechanical operations. Such shortening, however, tends to lead to a higher cyanide content in the final product. It is probable that the slight fermentation which occurs during pressing for longer periods contributes to the detoxification of the meal.

One gram of *gari*, when consumed, gives about 3.4 calories; but it contains only 0.015 g (1.5%) of protein. Like the fresh cassava tuber, *gari* supplies food energy and little else.

Gari is a dried form of cassava and can be stored for months at room temperature. It requires little further preparation before eating. As a snack, it can be eaten directly in the dry form. Alternatively, cold water can be added to it to form a suspension which is then eaten directly. However, the most widespread method of eating *gari* is to pour it into a quantity of boiling water to form a paste (*eba*) similar in consistency to pounded yam. Like pounded yam, the paste is eaten by dipping small balls of it in stew or soup, and swallowing without mastication. Most consumers prefer a paste of high viscosity ("draw"). This characteristic is due to partial dextrinization of the starch during toasting, so that when the product is put in hot or cold water, it swells considerably.

Gari occupies a very significant place in the diets of West African people, particularly urban dwellers. Its cheapness, ease of storage, and ease of preparation for consumption have combined to make it extremely popular among the urban masses who have very little money and very little time.

Farinha is the most common form in which cassava is consumed in Brazil and some other parts of South America. To prepare it, the fresh cassava tubers are washed, peeled, grated, pressed for a few hours, sieved, and then toasted in a shallow basin over a low life. *Farinha* is therefore very much like *gari* in its mode of preparation. The only difference is that the pressing and fermentation times for *farinha* are much shorter. The method of consumption of *farinha* is also very much like that of *gari*: it can be eaten dry, or mixed with hot or cold water to form a paste.

The production of *farinha* in Brazil has been mechanized for several decades. Power graters, power pressers, and rotating ovens are routinely used in its production. With these machines, it is possible to process over 30 tonnes of fresh tuber at each processing plant per day. One tonne of fresh roots yields 0.35-0.40 tonnes of *farinha*.

Atieke is a popular form of processed cassava in Côte d'Ivoire. It is made from pulverized cassava which is fermented and then steamed. It has a shorter shelf life than either *gari* or *farinha*.

5.2.5 Meal of retted cassava

This is produced by steeping the fresh cassava tuber in water for several days until it has softened. The softened pulpy mass is then disintegrated in water and passed through a coarse sieve. After passing through the sieve, the meal is allowed to sediment, then the semi-solid suspension is packed in cloth bags and squeezed slightly to expel the excess water. The final meal that results is white and crumbly.

The consumption of the meal of retted cassava is most prevalent in the rural parts of West Africa and in the Congo basin. The steeping of the tubers in water may be done in household tubs or pots, or stream banks. It is important that all parts of the tuber be submerged in water. Exposed portions will fail to soften. Peeling may be done before or after the retting has occurred. The steeping of the tubers in water serves to reduce the cyanide content.

The meal of retted cassava is usually cooked before it is eaten. It is rolled into large balls, boiled in water, pounded, and then eaten in the same manner as pounded yam or *eba*. One negative feature of the meal of retted cassava is that it tends to have a bad odour. This has restricted its popularity, particularly among city dwellers.

In the Congo basin, the retted cassava is made into a product called *chikwangue*. The retted cassava tuber-pieces are pounded into a paste, some of the larger fibrous strands being removed while pounding. The paste is wrapped in leaves and steamed until well done. It is then wrapped in leaves and stored. In this form it will keep well for up to a week.

5.2.6 Cassava flour

Cassava flour for human consumption is made when using low-cyanide types by drying (usually sun-drying) cassava tuber pieces, then milling them. The fresh roots are peeled, washed and cut into large longitudinal pieces. They are allowed to dry thoroughly in the sun and can then be stored. When the flour is needed, the dried pieces are milled to produce a greyish-white flour. The flour is prepared for consumption by pouring it slowly into a pot of boiling water over a fire, and stirring it on the fire until it forms a brownish, viscous paste. The paste is allowed to cool and harden, and is eaten with stews or soups. Flour production by this method is very popular in Tanzania and other parts of East Africa. Where high-cyanide cultivars are used, the tubers are retted for 2 or 3 days before being sun-dried. *Lafun* in south-western Nigeria is made in this way.

More recently, attempts have been made to produce from cassava a more refined flour suitable for baking bread, biscuits, etc. The ordinary cassava flour used for paste has very large particle sizes, and the main refinement has been to produce cassava flour with finer particles. Such flour can then be mixed with wheat flour for baking, and thus acts as a partial substitute for wheat flour.

5.2.7 Cassava chips and pellets

Cassava chips and pellets are produced mostly for feeding livestock. For the production of chips, the fresh tubers are washed, peeled, and cut into slices 3-6 cm long. The slices are then dried, and bagged. Pellets are produced from chips. After the chips have been dried, they are ground and hardened into cylindrical pellets about 2 cm long and up to 1 cm in diameter. It is in the form of chips and pellets that most of the cassava used for livestock feed in the temperate countries is imported. Pellets have become more popular than chips because they are denser and easier to handle. Thailand is one of the major suppliers of cassava pellets in the world market. Most of the present-day production of chips and pellets is highly mechanized and export-oriented.

A slightly different form of cassava chips is used for human consumption in certain parts of West Africa (Figure 6). The fresh tuber is peeled, boiled in water, and sliced into thin longitudinal slices (chips). The chips are then steeped in water for 1-2 days during which the water is changed once or twice. The chips can be consumed at this stage, but more commonly, they are removed from the water, and dried in the sun or over home fires for several days. This type of chip is a popular food for humans in south-eastern Nigeria, where it is called *abacha*.

5.2.8 Cassava starch

There is a high demand for starch in industry, and cassava starch has been used to satisfy some of this demand. The production of cassava starch for industrial use is a highly specialized and highly mechanized process. Tubers arriving at the production plant are peeled and washed. In the smaller factories, the entire peel is removed, while in larger, more efficient ones, only the outermost layer of the peel is removed. This conserves the small amount of starch present in the rest of the peel. After peeling and washing, the tubers are crushed (rasping) to produce a pulp. The pulp is suspended in water, and by means of a series of revolving screens, the fibrous material is removed, leaving the starch milk. Water used for this extraction stage should contain about 0.05% sulphur dioxide to prevent microbial action or fermentation during the extraction. The starch milk is passed through a sand cyclone to remove sand and dirt particles; then the starch is allowed to settle in tanks. Alternatively, a centrifugal separator is used to remove the water from the starch. The starch is then dried to a moisture content of 10-14%, after which it is pulverized, dry-screened, and bagged. Like other industrial starches, cassava starch finds its way into factories for producing glucose, textiles, and confectionery. Cassava starch grains vary in shape, and in size from 5-35 m. The amylose content is about 17%. Good quality starch should have a pH of 4.7-5.3, a moisture content of 10-13.5%, an ash content of less than 0.2%, and should be uniformly white in colour.

Grocery *tapioca* (*sago*) is essentially cassava starch produced by a special process. Before the starch is dried, it is put on a sheet of metal previously smeared with oil, and placed over a fire. It is stirred to prevent burning. The starch grains expand, and there is partial dextrinization, causing the particles to adhere together. The final product is more digestible than ordinary cassava starch. Tapioca *flakes* are prepared by spreading the starch in a thin layer on the pan, cooking for about two minutes, and drying at 50°C to a moisture content of 12%. Tapioca *pearls* are made by first granulating wet starch, then gelatinizing them by roasting for 15 minutes on hot pans smeared with coconut oil. They are dried at 40-50°C in a stream of hot air for about two hours.

A certain amount of direct consumption of cassava starch occurs among certain groups in the Niger delta in West Africa. The starch, after extraction, is stirred with boiling water to form a thick semi-solid paste, which is then eaten.

5.2.9 Cassava leaves

The use of cassava leaves and tender shoots for human consumption is widespread in Africa. It is particularly prevalent in Sierra Leone, and in the Congo basin. The leaves are chopped or crushed, boiled, and then consumed. They may be eaten by themselves, or incorporated into stews or broths. *Pondu* is a delicacy made from cassava leaves and widely consumed in West and Central Africa.

Cassava leaves are nutritious food. The composition is given in Table 4. The leaves are much richer than the tuber in proteins and vitamins, especially vitamins A and C. The only requirement is that the leaves be sufficiently detoxified before being eaten. This is accomplished by crushing or chopping, and subsequent boiling of the leaves.

Chapter 6

SOCIO-ECONOMIC CHARACTERISTICS: PERSPECTIVE, PROBLEMS, AND FUTURE PROSPECTS FOR CASSAVA.

6.1 GLOBAL PRODUCTION

The world production of cassava in 1990 is shown in Table 5. Most of the production comes from three distinct regions on three continents:

a) West Africa and the adjoining Congo Basin.

b) Tropical South America.

c) South East Asia.

The leading countries in terms of production are Nigeria, Brazil, Thailand, Zaire and Indonesia.

The trend in production during the decade of the 1980s has been generally upward, but for the regions where cassava is a major food item, per capita production has declined and production has failed to keep pace with population increase (Table 6).

6.2 CHARACTERISTICS OF THE CASSAVA DELIVERY SYSTEM

6.2.1 Labour requirement

At the traditional level, cassava production in the field requires only about 150 to 200 person-days per hectare. The major labour demanding operations are land preparation (40 person-days per hectare), weeding (45 person-days) and harvesting (70 person-days). The total labour required to cultivate cassava is much less than what is required to produce a hectare of yam or upland rice (Table 7). Yet cassava is a greater energy producer per unit area than most tropical field crops. Thus, the labour input per unit of energy produced is quite low. This low demand for labour has contributed immensely to the spread and sustenance of cassava cultivation. The popularity of cassava cultivation has been further enhanced by the flexibility of the timing of the labour input, since most operations in the cassava cultivation cycle (especially harvesting) can be delayed without grave reductions in yield or quality.

The low labour requirement for producing cassava must be seen against the background of two other factors. The first is that apart from labour, land is a major resource input for cassava production. Cassava stays in the field for a minimum of 9-12 months, and in the traditional setting could stay for up to two years. Thus, while cassava is a light user of the labour input, it is a heavy user of the land resource input. The second point is that while field cultivation of cassava may be low in labour demand, the entire delivery system for the crop is not necessarily so. It is estimated that processing of cassava may demand as much labour per hectare of harvest, as that expended in producing the crop (Dorosh, 1988). When high-cyanide cassava is grown as in West and

Central Africa, this labour input for processing is not optional, unlike what pertains to yams, cocoyams, or sweet potato. However, the processing of cassava, though demanding additional labour, has been critical to its versatility and popularity.

6.2.2 Heavy calorie yield

Cassava produces a higher amount of food calories per hectare than do most other tropical crops (Table 8). It produces more calories per hectare than yam, sweet potato, Irish potato, taro, rice, wheat, maize, or guinea corn (sorghum). When considered in terms of calorie yield per month, it is surpassed only by sweet potato, Irish potato, taro and maize.

6.2.3 Hardy plant characteristics

Cassava grows and yields reasonably well under conditions of environmental stress caused by low fertility or drought. This characteristic enables cassava to be grown in widely varying ecological zones. It also means that as human population pressure results in the cultivation of more marginal lands, cassava has progressively taken over land previously devoted to other crops. This phenomenon is very evident in a country like Kenya where population pressure has forced agriculture into hitherto unutilized lands, and there is a renewed interest in cassava as a crop for exploiting these lands. Similarly, the drought of the late 1980s that devastated much of the cereal-dependent agriculture in East and Southern Africa, has re-kindled interest in cassava as a security crop for drought years. The food security value of cassava is thus accentuated by its ability to produce under difficult conditions.

6.2.4 Ideal planting material

The planting material used for commercial propagation of cassava is the stem cutting. Unlike yam, where a significant proportion of the edible harvest has to be lamentably reserved for planting, cassava is propagated from the stem, a non-edible part of the plant.

6.2.5 Cheap, convenient staple

Cassava is the most frequently processed of the major tropical tubers. Historically, the processing of cassava, and the traditional technology for it, have arisen from the need to detoxify high-cyanide types which were (and still are) the mainstay of the major cassava-dependent diets. Processed forms are diverse, as has already been discussed. Apart from detoxification, processing for human food enables the product to acquire socio-economic characteristics which the raw produce does not have. The processed form is usually less bulky, more transportable, more storable, and easier to prepare for the table. These are precisely the characteristics that make a food item appealing to the urban masses. These factors have contributed in no small measure to the transformation of cassava from a traditional food for the rural areas, to a convenience food for the urban masses. *Gari* in West Africa, *farinha* in Brazil, and *kwako* in Guyana are typical processed cassava products that fit well into the urban demand. The next logical step will be to create a greater number of culinary forms that will fit into the fast food delivery system which today's urbanite seems to subsist on.

For all its suitability for the urban population, it appears that cassava is only tolerated by them because of its cheapness and convenience. Given a choice devoid of economic considerations, they would rather eat something else. Preferred over cassava are yams/rice in West Africa, cereals in South America, maize in East Africa, and rice in Asia. This means that as income increases, the individual is more likely to consume less of cassava and more of the preferred food. This has the peculiar effect of perpetuating the position of cassava as the "poor people's food". It also causes the richer policy-making elite to lose touch with cassava. Some of the consequences of the distancing of the policy-makers from the root crops have already been discussed.

6.2.6 International trade

Of all the tropical tuber crops, cassava is the most traded on the international market. In 1984, over 31 million tonnes of cassava were exported (Horton, 1988). Over two-thirds of the export came from Thailand, and the rest from Indonesia and China. The exports went mainly to the Benelux countries and Germany, and were used mainly for animal feed. Dorosh (1988) suggests that this trade was sustainable mainly because the EEC's common agricultural policy had a high levy on imported maize, and little or none on cassava.

6.2.7 Mechanization

One aspect of the cassava delivery system that has not advanced sufficiently in recent times is the mechanization of field operations. Cassava planters and harvesters are in use only in isolated pockets world-wide, and advances in this sector have not kept pace with the rapid development of cassava processing technology in recent years.

6.3 OUTSTANDING PROBLEMS OF CASSAVA

Cassava is a crop with relatively few cultivation problems. However, problems seem to be encountered when utilization is considered. The following are some of the problems involved:

(a) *Low protein content.* Even though the cassava tuber supplies a large quantity of food calories, its protein content is disappointingly low. Even the small amount of protein which it contains is of low quality. Consequently, peasant communities that rely heavily on cassava diets usually have a high incidence of protein malnutrition. Two types of approaches can be adopted to cope with the problem of low protein content in cassava. The first is to realize that cassava is a supplier of carbohydrates, and little else. It cannot be considered as a balanced food, and diets that contain it must be made to supply all the other items required to make a balanced diet. Cassava leaves, of course, contain significant amounts of protein, but their consumption is not as great and as widespread as that of the protein-deficient tuber. Indeed there is a need to further popularize cassava leaf consumption through extension programmes. Leaves could provide an effective protein supplement to go with tuber consumption. The second approach to the low-protein content of roots is to attempt to breed cassava cultivars that will have a high protein content. Unfortunately, nearly all the cassava cultivars that have been collected to date are low in protein, but the task is quite achievable using modern bio-technology.

(b) *The cyanide problem.* The need to detoxify most types of cassava tuber before they can be consumed, is a major constraint in utilization. In the traditional village setting, this has given rise to numerous laborious steps that must be dutifully performed before cassava can be consumed. Even in modern processing units, the need for detoxification still compels the introduction of one or two extra steps in the processing procedure. Where cassava is processed for starch and other industrial products, the cyanide content of the tuber is not significant, and may not constitute a problem. The ultimate solution to the cyanide problem lies in the breeding and selection of cultivars which contain little or no cyanide. It may be necessary in future to have two different sets of cassava cultivars: those for food and those for starch. In the former, a low fibre content and a low cyanide content would be the prime requirements. In the latter, a high starch content would be the main consideration.

(c) *Rapid deterioration of the fresh tuber.* It has already been pointed out that the fresh cassava tuber deteriorates if stored for more than a few days after harvesting. The economic consequences of this one characteristic are numerous. Firstly, it means that only fresh roots can be used at the processing plant. From the economic standpoint, it would be best if an entire cassava field could be harvested all at once and in one operation; but in a situation where fresh roots must be supplied to the factory daily, harvesting of the field can only be done on a piece-meal basis, and is therefore uneconomic. Secondly, the need for fresh tubers implies that harvesting must go on even during the dry season, when the ground is hard and digging is tedious. The only alternative, of course, is to shut down the processing factory for the duration of the dry season. Thirdly, cassava which is left unharvested for fear of deterioration, actually occupies land needlessly. On a global basis, millions of hectares are today occupied by cassava which is ready for harvesting, but which can only be harvested in small bits because the tuber cannot be stored.

The problem of inability to store the fresh cassava tuber is difficult to solve. Reports have shown that the tubers can be stored for some weeks under special conditions. However, it is doubtful if storage under such conditions would be economical, except for cassava that is grown as a vegetable for speciality markets. Investigations should continue in an attempt to devise more economical methods for storing the bulk of cassava tubers. Meanwhile, it seems that for processing, the storage of cassava tubers must continue to be avoided, and only freshly harvested tubers can be utilized.

(d) *Mechanization of planting and harvesting.* While the processing of cassava has reached advanced stages of mechanization, its planting and its harvesting are still performed by very crude methods. The harvesting of cassava has been particularly difficult to mechanize, partly because of the excessive foliage on the plants, and partly because of the awkward root geometry. The dispersal and popularization of existing machinery has only occurred to a limited extent. Breeding varieties with tuber shape suited to mechanical harvesting should be a priority.

(e) *Diseases*. Cassava mosaic disease, cassava mealy bug, and cassava bacterial blight are among the major diseases and pests which constitute a problem in cassava production. Efforts at producing resistant cultivars have met with success, and are expected to continue.

6.4 FUTURE PROSPECTS AND THE ROLE OF RESEARCH

One of the most promising factors in the future of cassava is that it has received more consistent and sustained research attention in the 1970s and 1980s than any of the other tropical tuber crops. Moreover, the cassava breeder has several advantages which the yam or cocoyam breeder would envy:

(i) the plant flowers regularly and, in some instances, continuously;

(ii) the male and female flowers are separated not only in space (monoecism) but also in time (protogyny), thereby making artificial hybridization relatively easy;

(iii) seed set is regular, and the seeds germinate fairly easily; and

(iv) genetically important plants can be easily multiplied by means of cuttings which root and sprout without difficulty; this is particularly important if the technology for tissue culture is not immediately available.

The potential for the improvement of the cassava crop is therefore very great. The recent research attention has already resulted in marked improvements in the cassava delivery system. Some of the innovations that have resulted, or are likely to result, in further improvements of the cassava delivery system include the following:

a) *Meristem tissue culture*, which has made possible the rapid multiplication of elite clones, the rapid world-wide dissemination of disease-free material, and increased efficiency in germplasm conservation.

b) *Biological control* of the cassava mealy bug and other pests of cassava. The beauty of biological control is that it can be integrated with other methods to free the traditional farmer from undue dependence on pesticides which are costly, difficult to procure, and sometimes environmentally harmful.

c) *Low-cyanide* cultivars with the desired yield, quality, and pest/disease resistance characteristics have been released. This will remove some of the proclaimed advantages of high-cyanide cassava, and still obviate the need for elaborate processing.

d) *Drought-resistant* cultivars have been identified, to permit the frontiers of cassava cultivation to be further pushed into drought-prone areas, especially in Africa.

e) *Disease-resistant* cultivars have been released which can tolerate the cassava mealy bug, the cassava bacterial blight, and the African cassava mosaic disease, three maladies that have for decades held down cassava productivity in various parts of the world.

f) *High-yielding polyploid* cultivars have been identified. There are already reports of triploids that can yield up to 76 tonnes per hectare (Hahn *et al*., 1991).

g) *Apomictic* lines have been identified that may eventually permit the commercial cultivation of cassava from true seed.

h) *Early-maturing* cultivars that can be harvested in 6-8 months have been released. This will permit cassava to be produced as an annual within the same growing season. This will affect the way cassava is used in cropping systems. However, the full benefit of this development will not be felt unless the factors that dictate piece-meal harvesting of cassava are fully resolved.

i) *Alley cropping* and other novel cropping systems will improve the sustainability and resilience of the cassava delivery system.

If the present research attention at both international and national research centres can be sustained, cassava cannot but have a promising future. Rapid improvements are expected in all stages of the cassava delivery system, and in its food security importance at the household and national levels.

SECTION B: YAMS

Chapter 7

BOTANY AND ECOLOGY OF YAMS

7.1 KINDS OF YAM

Yams are members of the genus *Dioscorea* which produce tubers, bulbils, or rhizomes that are of economic importance. They are considered to be monocots, despite occasional evidence (Lawton and Lawton, 1969) of the existence of a second cotyledon. They belong to the family Dioscoreaceae within the order Dioscoreales (Ayensu, 1972). The genus *Dioscorea* is by far the largest genus of the family. Cytologically, yams have a basic chromosome number $n = 10$, but various degrees of polyploidy exist even within the same species. Thus for *D. bulbifera*, different races with $2n = 40, 60, 80$ or 100 chromosomes have been reported Similarly for *D. esculenta*, Miege (1954) reported $2n = 40$, while Raghavan (1958) reported counts of 90, and 100. Some of the highest chromosome counts have been found for *D. cayenensis* where $2n = 140$. In general, the highest chromosome numbers and the smallest chromosome sizes occur in the more tropical *Dioscorea* species, while the smallest numbers and largest sizes occur in the more temperate species.

Within the genus *Dioscorea*, the most important species, from the economic point of view, are *D. rotundata, D. alata, D. cayenensis, D. esculenta, D. dumetorum, D bulbifera, D. trifida, D. opposita, D. japonica,* and *D. hispida.* Taxonomically, the genus *Dioscorea* is subdivided into sections within which the species fall. The section Enantiophylum contains most of the economically important yam species (*rotundata, alata, cayenesis, opposita,* and *japonica*) and is characterized by the fact that the vines twine to the right, i.e. in a clockwise direction when viewed from the ground upwards. Species in sections Lasiophyton (*D. dumetroium,* and *D. hispida*), Opsophyton (*D. bulbifera*), Combilium (*D. esculenta*) and Macrogynodium (*D. trifida*) twine to the left. The various species of edible yams will be discussed with respect to their characteristics, origins, natural distribution, extent of cultivation, and cultivars within the species. The species are discussed in their approximate order of importance on a world-wide basis.

***Dioscorea rotundata* Poir** (white yam, white guinea yam) is grown on a greater hectarage than any other yam species in the world. The stem twines to the right, and will usually grow to a length of several metres. The stem is wingless, and is roughly circular in cross-section. Spines, as well as a whitish bloom, are present on the stem, but the extent of these characteristics varies greatly among cultivars within the species, and perhaps also within the same cultivar under different environmental conditions. The leaves are simple, cordate, and usually pointed at the tip; the leaves are opposite in their arrangement. Neither stems nor leaves have any hairs. The tuber is more or less cylindrical in shape. The skin of the tuber is smooth and brown, while the flesh is usually white and firm. Starch grains in the tuber are large and ovoid.

Dioscorea rotundata is native to West Africa, but it does not occur in the wild, and it probably developed in cultivation from *D. praehensilis* Benth. Today, *D. rotundata* remains the principal yam cultivated in West Africa -- the most important area in the world for yam production. The extent of its cultivation parallels the preference of the inhabitants of this region for this type of yam over most other kinds. Its cultivation has also spread to other parts of the world - it is grown extensively in the West Indies, and to some extent in East Africa. However, there is little or no cultivation of *D. rotundata* in Asia.

There is a very large number of cultivars and land races of *D. rotundata* that are grown especially in West Africa where it originated, and is most widely cultivated (Waitt, 1961a). Unfortunately, the taxonomic position of most of these cultivars, and of cultivars of yam in general, is somewhat confused.

Dioscorea alata **L.** (water yam, greater yam) is the most widely distributed species of yam, though the total quantity produced is less than that for white yam. The stem possesses four or more rows of wings, so that it is more or less stellate in cross section. The wings are also present on the petioles. At the junction of the petiole and the stem, the wings widen to form auricles. The stem is usually green, but in some cultivars the wings may be purple or reddish in colour owing to anthocyanin pigments. The stem twines to the right. There are no spines on the stem, except occasionally at the bases of very large stems. The leaves are ovate and opposite in arrangement. They are generally larger and lighter green in colour than leaves of *D. rotundata*. Many cultivars have varying degrees of purple coloration in the leaves. Tuber shape is extremely variable, although most are cylindrical. Tuber flesh is white or purplish, and loose ('watery') in texture. Many cultivars of *D. alata* possess a thin layer of tough sclerenchymatous fibres just below the tuber skin. This layer is absent in most other kinds of yam.

Most cultivars of *D. alata* do not normally flower, but in those that do, the male inflorescences arise as panicles and the female ones as small spikes, in the leaf axils.

Dioscorea alata originated in south-east Asia, probably in Burma. From there it first spread to India, Malaysia, Indonesia, and the eastern portion of south-east Asia. Later it served as food for voyagers, and was thereby spread to other parts of the tropics. Immigrants from India and Malaysia introduced it to Madagascar, from where it was probably introduced into East Africa. Portuguese and Spanish voyager-traders of the 16th century probably introduced it into West Africa and later to the West Indies. Today, *D. alata* is the most widely distributed of all the yams. It is grown in nearly all parts of the tropics. It is the most extensively cultivated species of yam in the West Indies, the Pacific Islands, and tropical Asia. In West Africa, its extent is next only to that of *D. rotundata*. It is unknown in the wild state.

Several cultivars of *D. alata* exist, being distinguished by tuber and shoot characteristics. In addition, the extent and distribution of anthocyanin pigmentation on the stem and leaves can be used to distinguish the cultivars. From his world-wide collection of *D. alata* lines, Martin (1974) has evaluated, selected, and described several promising varieties. Among these, Florido, Forastero, and Gemelos from Puerto Rico, Leone Globe from Sierra Leone, Farm Lisbon from Trinidad, and Veveen from Nigeria seem to be promising. Other identified varieties are Toki, Kinampay, Kinabayo, Kabusah, Binugas, Gunung, Purmay and TDa 291.

***Dioscorea cayenensis* Lam.** (yellow yam, yellow guinea yam) (Figure 7) is, in many respects, similar to *D. rotundata*. Indeed some francophone authors regard *D. rotundata* as a sub-grouping of *D. cayenensis*. However, more recent DNA studies have led to the opposite suggestion that *D. cayenensis* is a taxonomic variety of *D. rotundata* (Terauchi *et al.*, 1992). The yellow yam gets its common name from the fact that its tuber flesh is usually yellow in colour, although variants which are almost white do occur. The yellow colour is due to the presence of carotenoids. The tuber skin is firmer and less extensively grooved than that of *D. rotundata*, and the corm at the head of the tuber is also more massive. The leaf is slightly bigger, and the leaf tip less pointed, than for *D. rotundata*, giving the impression of a more rounded leaf. The leaf lamina is also more deeply indented near the petiole. The vein grooves are less distinct, and the lamina surface is darker and glossier than that of *D. rotundata*. The stem twines to the right and possesses thorns, but the stem itself is usually devoid of bloom. Physiologically, *D. cayenensis* differs from *D. rotundata* in having a shorter period of tuber dormancy, and a longer growing season. Thus it can only be grown in areas (e.g., the forest zone) where the rainy season is slightly longer than the minimum required for *D. rotundata*.

Dioscorea cayenensis is native to West Africa, where it occurs in the wild state, as well as under cultivation. It was introduced into the West Indies from West Africa during the 16th century. Today its cultivation is mainly confined to these two areas, and no significant amounts are grown in Asia.

Many cultivars of *D. cayenensis* exist, but very little work has yet been done to identify and describe them (e.g., Waitt, 1961a). However, the degree of variation within this species is small in comparison with *D. rotundata* or *D. alata*, so that the number of varieties is also much smaller.

***Dioscorea esculenta* (Lour.) Burk.** (lesser yam, chinese yam, Asiatic yam) has a stem which twines to the left. The stem is thin, often pubescent, bears spines, and is cylindrical. Leaves are few, simple, broadly cordate, light green in colour, and arranged alternately on the vine. The base of the petiole is enlarged by three or four prominent spines. Spines also occur on the roots, but not on the tuber-bearing stolons. The tubers (Figure 8) are small and characteristically borne in clusters by each plant, unlike most other yams which usually produce only one or two large tubers per plant. Each tuber is borne at the end of a stolon which may be 5-50 cm long. Each plant of *D. esculenta* may produce 5-20 tubers. Each tuber is almost cylindrical, with rounded ends. Mature tubers measure 8-20 cm in length, 2-5 cm in diameter and 100-200 g in weight. Some New Guinea varieties weigh up to 3 kg. Tubers have thin, smooth, yellowish-brown skins. The tuber flesh is white, and less fibrous than that of most other yams. After cooking, the texture is softer, and the taste sweeter than that of other yams. Starch in the tuber is more finely grained than that of other yams, cassava, or sweet potato. Particles are generally less than 0.5 m in diameter.

Dioscorea esculenta originated in Indo-China, and has been cultivated in China since at least the 2nd century A.D. Papua New Guinea is a major centre of diversity for this yam. Its cultivation has now spread throughout the tropics, and even to Africa, where it was unknown until recently. Even though it is cultivated throughout the tropics, its production is most important in south-eastern Asia, the South Pacific Islands and the West Indies. Wild types of *D. esculenta* also exist in Malaysia, Papua New Guinea, and the Philippines. Flowering is rare in cultivated types.

Dioscorea dumetorum **(Kunth) Pax** (bitter yam; trifoliate yam) has a hairy stem which twines to the left. The leaves are trifoliate, a characteristic which distinguishes this yam from the others of major economic importance. The leaf, like the stem, is pubescent; each leaflet is ovate. Spines are present on the stem. The tuber is large and coarse; each plant may produce one tuber or a cluster of them. The tubers are bitter and, in many cultivars, poisonous because of a high content of the alkaloid dioscorine or its derivatives. It is therefore necessary that the tuber be steeped in running water or salt water and boiled before it is eaten.

Dioscorea dumetorum originated in tropical Africa, and occurs there in both wild and cultivated forms. Its cultivation is still essentially restricted to West Africa. The tubers of many of the wild forms are highly poisonous, and they are therefore used in southern Africa to prepare poisons for hunting and other purposes. Variations in type occur within the species, but distinct cultivars have not been identified and described.

Dioscorea bulbifera **L.** (aerial yam) (Figure 9) is characterized by the production of large numbers of bulbils (aerial tubers) on each plant. Each bulbil originates in the axil of a leaf. The cylindrical stem twines to the left and has no hairs or spines. The leaf is simple, large, and devoid of hairs or spines, hut may be covered with a bluish bloom in some varieties. The base of the petiole is enlarged into two ear-like projections (auricles) that encircle the stem. The axil of each leaf contains two bud primordia and a bulbil primordium (Okonkwo *et al.*, 1973). It is the bulbil primordium that gives rise to the bulbil in the intact plant; but if a stem cutting of *D. bulbifera* is planted, the bulbil primordium proliferates to give rise to shoot, roots, and tuber. The underground tuber of *D. bulbifera* is small in the Asian and African varieties, which are often grown for the bulbils; but the West Indian varieties do produce substantial underground tubers, for which they are grown.

Dioscorea bulbifera is the only edible yam species that is native to both Asia and Africa. Wild forms of it can be found on both continents. The Asiatic varieties produce hulbils that are generally less angular, more spherical, and less toxic than the African ones. The cultivation of the species is most prominent in the West Indies and the South Pacific Islands. Martin (in U.S.D.A 1974b) has tested and characterized several different cultivars of *D. bulbifera*. The cultivars included Sharp Angled, Round, and Smooth Angled obtained from Puerto Rico, Sativa from India, Olode from Nigeria, Poison from

Hawaii, and Thuma from New Caledonia. Among these cultivars, the greatest yield of bulbils was from Thuma (19.5 tonnes per hectare), while the greatest yield of underground tubers was from Poison (22.1 tonnes per hectare) which also had the highest combined yield of bulbils plus underground tubers (32.7 tonnes per hectare). It is clear that the preferred cultivar in any locality will depend on whether the bulbil or the underground tuber is the main product desired. The degree of toxicity or bitterness of the tuber may also be as important a factor as the total yield.

***Dioscorea trifida* L.** (cush-cush yam) has vines which twine to the left and, like *D. esculenta*, produces many individually small tubers per plant. The stem is rectangular in cross-section, with the angles sometimes extended to form wings. The leaf is simple, but is deeply divided into 3-5 lobes. The petiole is winged. Neither leaves nor stems bear spines. Staminate flowers are borne in racemes while the pistillate flowers occur as spikes. The tuber flesh is white, yellow, pink, or purple, and is highly palatable.

Dioscorea trifida originated in the northern part of South America, and is the only yam of New World origin to attain any significance as food. Cultivation is restricted to the West Indies.

***Dioscorea opposita* Thunb.** (cinnamon yam) is native to China and tolerates a colder climate than the other economically important yams. The stem is cylindrical and twines to the right, but usually not to heights greater than three metres. The leaves are simple and oppositely arranged. The tuber is thin but very long, and grows vertically downward into the soil, thereby making it very difficult to harvest. Bulbils occur in the leaf axils.

This species is cultivated in China, Korea, and southern Japan. It is used for medicinal purposes in China.

***Dioscorea japonica* (Thunb.)** very closely resembles *D. opposita* both in structure and in tolerance to colder climates. It is native to Japan, and is extensively cultivated in Japan and China. It is used for food and in traditional medicine.

The preceding are the species of *Dioscorea* whose tubers are used extensively for food and are therefore called yams. Numerous other species of *Dioscorea* exist which are only eaten occasionally or are not used for food at all.

7.2 MORPHOLOGY AND ANATOMY OF YAMS

The salient features of each of the various species of yam have been discussed above. The botanical characteristics of the yam plant will now be discussed in greater detail.

7.2.1 The root

Yams possess a fibrous root system which grows more or less horizontally within the soil and therefore lies close to the soil surface. Most of the roots occur within the top 30 cm of soil, and only very few of them penetrate deeper than 1 m.

The root system develops elaborately during the early part of the plant's life. If the plant has been propagated from tuber, the roots arise from the massive corm-like structure at the base of the stem; they are therefore adventitious. Even if the tuber sprouted without being planted, numerous short, stout roots arise at the base of the stem. These roots are relatively fat, attaining diameters of up to 3 mm. Once the tuber is planted, these roots elongate rapidly and become the main feeder roots of the plant. During the first six weeks after sprouting, the roots grow extensively through the soil, branching, becoming lignified, and developing external cork in the process.

A second type of yam root arises from the body of the tuber. Some species and varieties of yam may lack roots on the tuber, but most kinds of yam have thin, short roots on the tuber. These develop from the tuber as it grows, but apparently each of them is alive and functioning for only a short time. The roots on the yam tuber probably serve the same function of mineral absorption as do the ordinary feeder roots, but their effectiveness is probably limited by their fewness, their shortness, and their ephemeral nature. Adventitious roots may sometimes arise from the lower nodes of growing yam plants.

The roots of many yam species bear spines. Usually it is those species which have spines on the stem that also have spines on the roots. The wild types generally have more spiny roots than their cultivated relatives, which have been selected partly for their less formidable spines. In nature, these spines protect the tuber by making it more difficult for foraging animals to reach it.

The primary anatomical structure of the yam root resembles that of a typical angiosperm root (Ayensu, 1972). On the very outside is the exodermis, consisting of a single layer of thick-walled cells that are compactly arranged together. Within the exodermis is the cortex, which may constitute up to two-thirds of the root diameter and most of its hulk. Cortical cells are irregular in shape and separated by air spaces. The innermost layer of the cortex is the endodermis, most of whose cells have the typical thickening of their inner and radial walls, as well as a Casparian strip. The central stele is composed of a 3-4 layered pericycle, a xylem with numerous (twelve or more) points, a phloem which alternates with the xylem points, and a central pith composed of parenchyma cells with thick walls. Root hairs are present just behind the growing tip of the root.

7.2.2 The stem

The stem of yam is a rope-like structure which is unable to stay erect by itself. Instead, it circumnutates in search of a support on which to twine. The direction of circumnutation, and therefore of twining, is peculiar to each section of the genus *Dioscorea*. Enantiophylum yams circumnutate and twine in a clockwise direction going upward (i.e. twining to the right), while other yams circumnutate and twine in an anticlockwise direction (to the left). In most yams, the stem usually grows to a length of several metres before any branching occurs.

7.2.3 The leaf

There is considerable variation in the shape, size, and colour of yam leaves. In most cases, the lamina is simple and without serration on the margins. The tip of the leaf is pointed. Primary veins radiate from the base of the lamina, but the remainder of the venation is reticulate. Hairs are usually absent from the lamina. Leaf colour is usually green, but in the young leaves of some *D. alata* cultivars, the green colour may be masked by purplish anthocyanin pigments. The petiole is long, and may be winged or spined in species where the stem is winged or spined. The base of the petiole, where it attaches to the stem, may be variously modified: it may bear a set of prominent spines, as in *D. esculenta*; it may be dilated into ear-like auricles as in *D. bulbifera* and *D. alata*; or it may simply be swollen as in *D rotundata* and *D. cayenensis*. As with many other plants, the yam petiole is capable of growing or twisting in such a way as to expose the lamina to the maximal amount of sunlight. Leaf arrangement on the stem may be opposite or alternate, but the arrangement may vary even on the same plant. It is possible to propagate yams by means of stem cuttings, hut the resulting plant is usually devoid of vigour, and the tuber yield is small.

7.2.4 The flower, fruit and seed

Yams are normally dioecious, with male and female flowers produced on different plants. There are usually more male plants than female, and more male flowers on each male plant than female flowers on each female plant. Occasional instances of monoecism (male and female flowers on the same plant) have occurred. Many yam cultivars do not flower at all.

The male flowers are borne in panicles produced in the leaf axils. Each male flower is inconspicuous and small. There are three sepals, three petals, and three or six stamens. Neither sepals nor petals are brightly coloured, each one being greenish or whitish. The female flower is larger than the male and is borne in spikes in the leaf axils. It has three sepals, three petals, and an inferior ovary. The ovary has three locules, each of which contains two ovules. There are three stigmas.

Even though yam flowers are inconspicuous, their pollination is by insects. The pollen grains are sticky, and many yam species (e.g. *D. bulbifera*) produce scented flowers. Small night-flying insects are probably responsible for their pollination. It seems that, under field situations, a significant percentage of female yam flowers may remain unpollinated, thereby resulting in abortion and falling off of many young fruits.

The yam fruit is a dry, dehiscent capsule, 1-3 cm long. It is trilocular, and the junctions of the locules are extended out into flattened wings. When the fruit is mature and dry, it dehisces along the three sutures separating the locules, so that the seeds within the locules can be dispersed. Although each locule contains two seeds, one or both may fail to develop.

The yam seed is small and possesses a flattened wing structure which aids its dispersal by wind. The wing may completely encircle the seed (e.g. *D. rotundata*) or it may be present on one (e.g. *D. bulbifera*) or two sides only. The embryo of the seed is very small and it surrounded by the much larger endosperm region.

Quite often, in field situations, the yam fruit is still green and undehisced at the time that the plant dies back at the end of the season and remains so for several weeks. Apparently, maturation of the fruit and seeds continues long after the plant has senesced (Okoli, 1975). The yam seed normally undergoes a dormancy of 3-4 months after plant senescence. Once this dormancy is over, the seed germinates in three weeks after planting. The resulting seedling consists of a large cotyledonary leaf, and a small lateral growing point. The seedling eventually develops into a small viny plant, whose tuber yield is less than that obtainable from tuber-grown plants.

7.2.5 **The bulbil**

Certain yam species have the ability to produce bulbils. In such plants, bulbil production does not begin until the plant has matured to a certain extent. Then, as each new leaf begins to unfold, a bulbil develops in its axil. Production of bulbils will then continue until the end of the season, with old bulbils maturing and dropping off while new ones are formed closer to the shoot tip.

Bulbils may vary in colour from grey to dark brown; in shape from liver-shaped and angular, to spheroidal and rounded; and in weight from a few grams to over one kilogram. They are physiologically similar to the tuber, and can serve as a means of propagation.

7.3 ECO-PHYSIOLOGY OF YAMS

The *Dioscorea* yams are essentially tropical plants. Except for *D. japonica* and *D. opposita*, they cannot tolerate frost conditions (Coursey, 1967; Purseglove; 1972, U.S.D.A., 1972). Their growth is severely restricted at temperatures below 20°C and, generally, they require temperatures of 25-30°C for normal growth to occur. It is not known whether these temperatures, which allow for maximum shoot growth of the plant, are also the most conducive to tuber initiation and tuber growth. It is probable that the warm temperatures, by promoting considerable vegetative shoot growth and high respiration rates, may in fact retard tuber growth. Temperatures above 35°C greatly retard sprouting of the planted sett.

Yams thrive best when supplied with ample moisture throughout their growing cycle. Since most yams require 7-9 months from planting to harvesting, this means that they do best in areas where the rainy season is relatively long, and where there are fewer than four or five rainless months in the year. If yam must be grown where the dry season is longer, then supplemental irrigation may be needed.

The yam plant is relatively tolerant to dry conditions. In many yam-growing districts, planting is done during the dry season. The setts so planted in dry soil must remain there for 2-3 months before the rainy season starts. They not only survive this period, but actually commence to sprout before the rains come. Onwueme (1976) has shown that yam setts can survive and sprout without water. Even after sprouting, the yam

plant (seedling) is still able to tolerate periods of drought to a greater extent than many other crops. This is probably due to three factors:
i) the young yam plant, even if growing in a dry medium, is able to tap some of the moisture stored in the parent sett and thereby satisfy some of its moisture needs;
ii) the first phase of growth of the young yam plant is devoted mainly to developing the root system. Soon after sprouting, and even before field emergence, vigorous growth and ramification of the root system has begun, so that the plant is able to exploit whatever little moisture might be present in the substratum;
iii) the shoot (vine) of the young yam plant has an extremely xerophytic structure. Even when several metres high, the vine is devoid of expanded leaves, so that the total transpiring surface is considerably reduced. Even the stem, which is the main transpiring surface at this stage, is often heavily covered with a waxy bloom. These xerophytic features of the young yam vine are most pronounced in *D rotundata*, slightly less so in *D. cayesensis*, and even less so in *D. alata*. In some greenhouse experiments (Onwueme, unpublished) to determine how long newly emerged yam plants growing in soil could live without water, it was found that over 75% of the plants were viable enough to resume growth after being left unwatered for two months. During this dry spell, vine growth was restricted, and none of the leaves on the vines expanded. By contrast, well-watered yam plants of the same age had developed full canopies.

Moisture stress beyond the seedling stage is also well tolerated by the yam plant (Coursey, 1967). If yam plants growing in normal moist soil are suddenly deprived of water, the lowest leaves soon turn yellow and eventually senesce and fall off. Since a similar response also occurs when the plant is being supplied with water in insufficient amounts, the senescence and abscission of the lowest leaves may serve as a field indicator of moisture deficit in yams.

It is important to distinguish between the ability of a plant to survive drought or other adverse conditions, and its ability to survive and yield well. Even though the yam plant is able to survive many situations of drought, its ability to yield adequately thereafter is invariably sacrificed. Onwueme (1975b) has shown that moisture stress in the early part of the yam plant's life results in significant delays in the onset of tubering. Oyolu (1961) too has emphasized the importance of avoiding drought condidtions in the field between the fourteenth and twentieth week, a period during which vigorous tuber bulking occurs. Needless to say, the yam farmer is interested in yield, and not just the survival of his plants. It is therefore imperative that drought conditions be avoided in the field throughout the season. Yam plants that may have survived a drought and look healthy, will invariably give a disappointing harvest. It is for this reason that yams are not normally grown in areas where there are more than about four dry months in the year, unless irrigation is available. The crop can be grown in areas with as little as 400-600 mm of rainfall, but yields are generally low (King & Hackett, 1986a). Well distributed rainfall of over 1500 mm/year, or an equivalent amount of irrigation, is usually needed for commercial yam production.

Yams require soils of high fertility in order to do well. Marginal soils that can support cassava or sweet potato are of little use for yam production. For this reason, soils rich in organic matter are good for yam production since the organic matter supplies mineral nutrients in addition to improving soil structure. Many soils in the West African yam-growing zone are relatively rich in phosphorus. Moreover, the occurrence of mycorrhizae in association with yam roots facilitates phosphorus uptake, and enables yams to take up phosphorus from as little as 0.01-0.02 ppm in soil solution (King & Hackett, 1986a). However, nitrogen and potassium are often insufficient, and must be supplemented by fertilizers. Yam fertilizer recommendations in these areas, therefore, often call for nitrogen and potassium, or for nitrogen alone. Among the less sophisticated farmers, who still practise shifting cultivation, the high fertility need of yam is met by making it the first major crop when a piece of land is farmed after several years of bush-fallow.

In terms of soil texture, loamy soils are best for yam production. Sandy soils have a low capacity to hold nutrients and water, and are therefore unsuitable. Clays and heavy soils tend to become waterlogged and allow insufficient aeration for the yam roots and tuber. They also make harvesting difficult. Stony or gravelly soils should be avoided in yam production since tubers growing through such soils tend to be misshapen. For the same reasons, soils with a hard-pan and compacted soils should be avoided.

Perhaps as important as soil fertility and soil texture in yam growing is the soil drainage. Yams cannot tolerate waterlogging to any extent, and it is imperative that the soil be well drained. Poorly drained soils, and the resultant waterlogging, cause the roots and tubers to be poorly aerated and may result in tuber rot. The water table should be at least 90cm below the surface. The optimum pH tolerance for yams is 5.5-6.5. At pH less than 5.5, yams are very susceptible to aluminium toxicity. Indeed, yam is more sensitive to aluminium than either cassava or sweet potato. It has been suggested (USDA, 1972) that extremely acid soils should be corrected by liming, or avoided altogether.

Light is one of the environmental factors that play a critical role in yam production. Njoku (1963) has shown that the length of day plays an important role in tuber formation. Short days tend to favour tuber formation and tuber growth, while long days favour vine growth. Similarly, bulbil-producing plants of *D. opposita* produce more bulbils under short-day conditions than under long-day conditions. In addition, the senescence and die-back of the yam vine at the end of the season seem to be under some photoperiodic control (USDA, 1972), although reduced availability of water may accelerate the process. Different yam species vary in their sensitivity to this photoperiodically controlled senescence. *Dioscorea cayenensis*, for example, will continue to grow in the field for several weeks after *D. rotundata* and *D. alata* have shrivelled and died.

The influence of light intensity on yam growth and productivity has not been fully investigated. Several points suggest that yam is not a shade-loving plant. Firstly, yam plants grown in greenhouses or under some shade have often been observed to produce normal leafy canopies, but only to yield extremely small tubers (Onwueme, unpublished). Secondly, it is well established that yams grown without stakes yield less than those grown with stakes (Campbell and Gooding, 1962; Coursey, 1967; Lyonga *et al.*, 1973). The poorer yield of the unstaked plants is probably due to the greater amount of mutual leaf-shading that occurs there. Thirdly, the highest yam yields in the West African yam zone seem to occur at the northern limits of the forest zone and in the savanna zone. Deeper in the forest zone, the rainfall is heavier and lasts longer, but the frequent cloud cover probably limits the light intensity, and thereby limits the yield. It seems likely, therefore, that yam not only tolerates but requires high intensities of sunlight in order to be maximally productive. As with sugar-cane and several other tropical crops, it is probable that yam leaves are not light-saturated under normal daylight conditions.

7.4 PHENOLOGY OF YAMS

In a generalized growth cycle of the yam plant, four different phases are identifiable (Sobulo, 1972a; Njoku *et al.*, 1973) (Figure 10). For *D. rotundata*, the first phase lasts from the time of *emergence* until about six weeks later. During this time, the plant's growth consists almost entirely in developing a profuse root system, and in elongating the vine. Since leaf growth is negligible at this stage, the plant remains incapable of large-scale photosynthesis and must sustain itself by absorbing the food material stored in the parent sett. The dependence of the yam seedling on the parent sett is vividly seen if the seedling is disconnected from the sett soon after emergence. New growth of the vine, which had hitherto been robust, becomes spindly, and the general vigour of the plant is reduced.

The second phase is characterized by development of the foliage. Leaf expansion commences at about the sixth week. By the tenth week, the canopy is fully formed, and by the thirteenth week, little or no further increase in leaf area occurs. Root growth continues into this second phase, but by the tenth week, further net increases in root length are negligible. Some of the older roots wither and die as new ones are produced. Vine growth continues throughout the second growth phase. By the thirteenth week, however, the shoot tips show less vigour than previously, and some of them shrivel and die back. As a result, the formation of new leaves is drastically reduced. This, in conjunction with continuing senescence and abscission of some old leaves at the base of the plant, accounts for the stoppage in leaf area increase. This second phase of growth, with its drastic increase in plant leaf area, marks the transition of the plant from dependence on the sett to self-sufficiency (autotrophy). Indeed the latter part of this phase is a period of carbohydrate excess for the plant; and not surprisingly, tuber initiation occurs by the tenth or eleventh week (Onwueme, 1975a, 1975b). For species that produce flowers, flowering begins at approximately this time.

The third phase of growth is characterized by increase in tuber bulk. The large canopy of leaves and vines, which was formed during the second phase, now serves as a photosynthetic factory to manufacture food, which is stored in the tuber. Increase in tuber bulk continues until close to the end of the season. At this time, the fourth and final phase of the plant's growth cycle sets in. Large-scale senescence of the shoot begins, and, according to Sobulo (1972a), is accompanied by a decrease in the dry weight of the tuber. As has already been mentioned, the senescence and dying back of the shoot at the end of the season are probably under photoperiodic control. Onwueme (1977a) has reported that *D. rotundata* plots planted in November and in February senesced at approximately the same time, and did so at a time when moisture was still available to them. However, it is possible that, under many field situations, the end-of-season dying back of the yam plant is induced or accelerated by late-season diseases. After shoot senescence, the tuber enters into a period of dormancy, and will not normally sprout again until two or three months later. Yams other than *D. rotundata* also go through these same growth phases, but the exact duration of each phase will vary.

It can therefore be seen that the growth of the yam plant is divisible into phases during which one particular organ or set of organs exhibits greater growth in comparison to all others. Maximal root growth, shoot growth, and tuber and fruit growth follow in sequence. This raises several interesting questions about competition for dry matter (photosynthate) among the various organs of the plant. It could, for example, be asked whether it is the onset of tuber bulking that deprives the shoots of photosynthates and therefore causes cessation of shoot growth at the end of phase two (Onwueme, 1973); or is it the cessation of shoot growth that first occurs, thereby permitting excess photosynthate to be diverted to the tuber? Only further research can yield answers to these questions. It is most likely, however, that the synchronization of the various growth phases within the yam plant are endogenously controlled by plant growth hormones.

Chapter 8

THE YAM TUBER: FORM AND FUNCTION

8.1 TUBER FORM

The structure of the yam tuber is highly variable, depending on the species. Both genetics and environment play significant roles in determining tuber shape and size. Tubers of every imaginable shape have been produced (Coursey, 1967). Sizes of individual tubers may range from a few grams to over 50 kg, and tuber lengths of 2-3 m have been recorded. Most commercial yam tubers are more or less cylindrical in shape (Figure 11) and covered by a thick layer of cork. Cracks are often present on the tuber surface. Some roots may be present on the tuber.

As detailed below, the yam tuber grows from a massive, corm-like structure (the primary nodal complex) located at the base of the vine. Indeed, this corm is present very early in the life of the plant, being formed shortly after sprouting occurs. The main feeder roots, and later the tuber, arise from it. After harvesting, the corm may remain attached to the tuber but can be separated from it by breaking the narrow junction between them. Roots attached to the corm or to the body of the tuber, may also be present on ware yams brought to market.

Some authors consider the corm as an integral part of the tuber, and therefore refer to it as the 'head' of the tuber. This view may have arisen from the fact that many market yams still have the corm attached, although it is probably erroneous because the corm, being at the meeting point of the stem, tuber, and root, cannot be said to belong to any of the three unless supported by strong organographic evidence. Moreover, roots, and sometimes attached vine sections, do not automatically become part of the tuber just because they also accompany the tuber to market. Finally, it should be noted that the corm is present even in plants that cannot, or have not been induced, to form tubers. It seems, therefore, that it is best to regard the corm as a separate structure from the tuber, but one which can profoundly affect tuber functioning if both structures remain attached to each other. The tuber, at harvest, is devoid of buds on its body; but the corm has several buds present. If corm and tuber are attached until the end of the dormancy period, sprouting will usually occur from the corm, but if this has been removed, sprouting will occur from the head-end of the tuber near the point of the previous attachment to the corm.

The size of the corm varies according to species. It is usually massive in the wild species of *Dioscorea*. It is large also in *D. cayenensis*, but it is relatively small in *D. rotundata* and *D. alata*.

Anatomically, the mature yam tuber is surrounded by several layers of cork which have been produced by successive cork cambia forming one beneath another (Figure 12). The cork cells are arranged in radial rows. Just internal to the cork is the cortex, which is composed of thin-walled cells with very little stored starch. Beneath the cortex is a ring of meristematic cells, composed of several layers of tangentially elongated, thin-walled cells that are arranged in radial rows. It is this meristematic layer, lying only a few millimetres from the tuber surface, that gives rise to the sprout. The central portion of the tuber, by far the largest part of it, is occupied by the ground tissue. This is composed of thick-walled cells densely filled with starch grains. Vascular bundles ramify through the ground tissue. Each vascular bundle is collateral, having phloem towards the outside of the tuber, and xylem towards the inside. The xylem is devoid of vessels, and consists mainly of tracheids and xylem parenchyma. The phloem is composed of sieve-tubes, companion cells, and phloem parenchyma. The starch grains are rounded or elliptical, and are generally most concentrated in the parenchyma cells surrounding the vascular bundles.

Cells containing bundles of crystals (raphides) are common in the yam tuber, as well as in nearly all parts of the yam plant. These crystals presumably account for the itchiness of the raw tuber when eaten or placed in contact with the skin. Tannin cells are also present in yam tubers.

8.2 TUBER FUNCTION

8.2.1 **Tuber formation in yam**

8.2.1.1 *Origin and initiation of the tuber*

The yam tuber has conventionally been classified as a stem structure. Burkhill (1960) and Njoku (1963) have advanced strong organographic evidence to show that it is a stem, not a root, structure. Also the growing-point lacks any structure analogous to a root cap. However, several characteristics of the yam tuber tend to suggest that it is not a stem tuber in the classical sense that an Irish potato tuber or a cocoyam cormel would be. Firstly, the yam tuber lacks any scale leaves on its surface that might identify nodal positions. Secondly, no buds or 'eyes' are present on the surface of the yam tuber, nor are any preformed ones concealed beneath the surface (Onwueme, 1973). Thirdly, the growing point of the yam tuber is not marked by a terminal bud. Fourthly, most yam tubers, with the exception of some varieties of *D. esculenta* (USDA, 1974b), exhibit strong positive geotropism.

The yam tuber is probably neither a root nor a stem structure. Rather, it is a structure that originates from the hypocotyl - the transition zone between the stem and the root. This conclusion is supported by several morphogenetic studies which suggest that the yam tuber is a lateral outgrowth from the hypocotyl region of the plant axis (Martin and Ortiz, 1963; Lawton and Lawton, 1969).

The first event in tuber formation in most yams is the onset of meristematic activity at the junction of the stem and root (hypocotyl region). This meristematic activity results in the production of an amorphous mass of cells which is usually white in colour but may be pigmented in some *D. alata*. This mass of cells soon organizes a growing point and the structure begins to elongate. At this stage, the organ can be distinguished as a young tuber. The primary meristem remains at the young tuber's growing-tip, which is distal from the point of attachment to the hypocotyl. As will be discussed later, further growth of the tuber is accomplished by the production of new cells by the primary meristem, and the enlargement of the cells produced. Tuber development in *D. esculenta* differs from the typical pattern in that tuber formation is preceded by production of a stolon-like structure (Ferguson, 1973; USDA, 1974a). The tips of these stolons then swell and accumulate starch, thereby giving rise to the tuber. Since the tubers of *D. esculenta* are formed from stolons, and since some of them become negatively geotropic during growth, it is possible that their organ derivation differs from that of other yam tubers.

8.2.1.2 *Effect of environmental factors on tuber initiation*

Tuber formation (initiation of tubering) is influenced by several factors of the environment (Posthumus, 1973). In this context, distinction should be made between the influence of these factors on tuber initiation, and their effects on subsequent tuber growth. The former will be considered now, while the latter will be taken up later.

Njoku (1963) has shown that tuber initiation in yam is promoted by short-day conditions. In most parts of the tropics, day-lengths are naturally short throughout the year, never much exceeding twelve hours. As such, tuber initiation in yam should occur readily at any time of the year. Initiation of the tuber should therefore not be a problem when year-round or out-of-season production of yam is contemplated in the tropics. The influence of light intensity on yam-tuber initiation is not known, but since yam tubers have been known to produce new tubers while resting on an illuminated shelf (Onwueme, 1975b), light probably does not prevent tuber initiation in yams. Moisture stress has been found to delay tuber initiation in *D. alata* yams (Onwueme, 1975b).

One peculiar factor which affects tuber initiation in yams is the length of time for which the parent tuber was stored (since harvesting) before it was planted i.e. the *physiological age* of the parent tuber. Onwueme (1975a) showed that tubers which were stored for only a short time sprouted later, and grew for a longer time after sprouting before initiating tuber. Tubers that had been stored for a long time sprouted more readily and initiated tuber fairly rapidly. This behaviour of long-stored tubers is not necessarily advantageous under field conditions. Sometimes tuber initiation may begin before appreciable leaf-canopy formation has occurred. A vicious circle is then established whereby competition from the new tuber for photosynthate retards further canopy formation, while the paucity of canopy already formed means that eventual tuber size will be small. Ideally, therefore, best yield will result if the plant can devote its early life exclusively to canopy formation, before tuber initiation. In cases of extremely long tuber storage, the yams may begin to initiate new tubers even before they are planted (Onwueme, 1975b). It seems likely that, as with some other plants (Wareing, 1973), these tuber-initiation processes in yam are under the control of endogenous growth hormones. Concrete proof for this is, however, lacking at present. Attempts to hasten tuber initiation by kinetin application to the hypocotyl region of *D. rotundata* has been unsuccessful (Onwueme, unpublished). Udebo (1971) has reported that bulbul formation in *D. bulbifera* cultures was increased by addition of auxin or kinetin, but again it is not known whether these two growth substances operate endogenously to regulate bulbul initiation.

8.2.2 Tuber growth in yam

After its initiation, the tuber commences to grow. In yam, the same primary meristem which was involved in tuber initiation is also involved in subsequent growth. Once polarity has been established, the primary meristem at the distal tip of the tuber continues to divide and produce more cells. The cells produced enlarge, and, in time, become engorged with stored starch. Increase in tuber size is therefore due to production of new cells by the primary meristem, and their subsequent enlargement. As the primary meristem is pushed farther and farther from the proximal tuber portion, it leaves a thin strip of meristematic cells beneath the cortex. Later, parenchymatous cells lying beneath the epidermis will become meristematic, produce cork cells, and isolate all cells external to them, causing them to shrivel and be sloughed off. Successive deeper-lying layers of parenchymatous cells repeat the process, so that any mature part of the yam tuber is covered by several layers of cork that have resulted from successive periderms. This cork protects the tuber from damage, pathogens, and water loss, within the soil and after harvesting. Even when the tuber is harvested prematurely, as may sometimes happen in double-harvesting (see Chapter 11), the process of cork formation continues during storage until the cork forms an effective water-resistant seal over the entire tuber. This process is seen visually as a gradual browning of the tail-ward tuber portions which were white at harvesting. The whole art of curing yams after harvesting is aimed at keeping them under conditions that will promote maximal rate and amount of cork formation. Cork formation is only one aspect of suitable tuber maturity for harvesting, which will be discussed further in subsequent chapters.

The pattern of growth of the entire yam tuber is a typical sigmoid pattern. Tuber growth is slow during the period following tuber initiation, very rapid for several weeks following the formation of full canopy, and again slow towards the end of the season (Campbell *et. al.*, 1962b; Chapman, 1965; Sobulo, 1972a; Ferguson, 1973). As has been suggested by Sobulo (1972a), there may, in fact, be a decrease in the dry matter of the tuber during the last month or so before shoot senescence.

The primary source of material for growth of tuber is the shoot where photosynthesis is occurring. The photosynthates produced there supply energy for the growth processes of the tuber, and serve as material (starch) for storage in the tuber. It follows, therefore, that the more extensive the leaf area during the time of active tuber growth, the more rapid is the rate of tuber growth. For this reason, early canopy formation is important in yam production.

Some evidence by Onwueme (1975b) suggests that the shoot may not be the only source of carbohydrates for storage in the tuber. It was found that long-stored tubers of *D. rotundata* produced sizeable new tubers at a time when the shoot was still submerged and could not have photosynthesized. The inference, therefore, was that material for the new tubers must have come directly from the old tuber. This suggestion may help to explain two peculiarities of yam production. Firstly, the well-established fact that large setts give higher yields than small setts (Miege, 1957; Coursey, 1967) may be partly because a large sett is potentially able to supply a greater amount of stored food directly to the new tuber. Even in instances where there is partial sett-decay after planting, a large sett is likely to have a greater amount of undecayed food material for transfer to the new tuber. Secondly, yams are notorious for the large plant-to-plant variation in yield obtained for plants that have been treated identically (Onwueme, 1977b). One possible explanation is that when setts of the same weight are planted, they decay to different degrees, so that the net weight of material available for transfer to the new tuber will vary.

The shape of the yam is determined primarily by its species and variety, and there exists an almost infinite array of shapes of yams (Coursey, 1967; Waitt, 1961). However, within the limits set by its genetic make-up, tuber shape can be influenced by certain external factors. Soil structure is one major determinant of tuber shape. If the tuber encounters a hard-pan during its downward penetration, its tail-end portion tends to become broader and more amorphous. As will be discussed later, this situation is often encountered under field conditions when yams are planted on the flat. Rocks and gravels in the soil also tend to cause the tuber to assume amorphous shapes. The impression, therefore, is that the developing yam tuber is to some extent malleable, so that physical obstructions in the medium in which it is growing will cause it to alter its shape. In this context it is worth mentioning that some farmers, who must grow very long yams for ceremonial purposes, often grow them in hollowed out logs where soil resistance is minimal, and the log prevents excessive increase in girth. Such yams may exceed 100 cm in length.

The factors responsible for branching in yam tubers have not been fully explored, but the tendency to branch is a varietal characteristic. In general, *D. alata* tubers tend to branch more frequently and elaborately than *D. rotundata*, which in turn branches more than *D. cayenensis*. Presumably what happens is that there is a cleavage in the primary meristem, so that the two or three separate meristems which result proceed to grow as separate branches. An attempt (Onwueme, unpublished) has been made to impose such a cleavage on a growing tuber by dividing the meristem with a piece of sterile plastic. The plastic was left in place and the tuber covered up again with earth. The expected branching was not observed when the tuber was uncovered again two months later.

8.2.3 Tuber sprouting and dormancy

For decades, it was believed that the yam tuber was similar to the potato in possessing buds at various points on the tuber surface, and that sprouting simply involved the breaking of these buds and their subsequent elongation. However, Onwueme (1973) showed that, at harvesting, the yam-tuber surface is normally devoid of buds, a conclusion supported by Martin (in USDA, 1974a). Later on during storage, one or more buds may develop from the head-region of the tuber, or from the corm, if it is still present. After planting, even budless tuber-pieces from the middle or tail portions of the tuber are capable of developing buds and sprouting.

The process of sprouting in budless tuber-pieces of yam has been described by Onwueme (1973). First the layer of meristematic cells just beneath the tuber surface begins active cell division, and produces a large mass of undifferentiated cells (Figure 13). This mass of cells soon becomes organized and a shoot apex becomes differentiated within it. At this stage, the overlying tuber skin has ruptured, revealing, on the surface, the glistening mass of cells produced by the meristematic activity. Such a point of skin rupture and exposure of the underlying cells during yam sprouting is called a *sprouting locus*. Soon the growing-point begins to push through the overlying mass of cells, and later it becomes visible from the surface as a small bud. The whole process from the onset of cell division till the bud is externally visible lasts 1-2 weeks, the time being slightly shorter for *D. alata* than for *D. rotundata* and *D. cayenensis*. If the tuber is in a moist medium, the bud will immediately proceed to elongate, and a ring of stout roots forms at the junction of the bud with the tuber. When the bud has elongated to become a vine, the region of its junction with the roots and old tuber remains stout and massive. This massive structure constitutes the corm. The new tuber will eventually develop as an attachment to it.

The rapidity with which a piece of yam tuber sprouts depends on which part of the tuber it has been obtained from. If the entire tuber is planted, sprouting invariably occurs at the head-region; and while the head sprout remains, sprouting in the middle or tail regions of the tuber is suppressed. Similar behaviour is exhibited by tubers which sprout during storage. However, middle and tail portions of the tuber are able to sprout when severed from the head. In such cases the tail and middle setts sprout much less rapidly than the head sett (Miege, 1957; Coursey, 1967). No differences have been found between the rates of sprouting of middle and tail setts (Onwueme, 1973).

When any yam sett sprouts (tail, middle, or head), the sprout tends to arise from the head-ward (more mature) part of the sett. It has also been reported (Onwueme, 1973) that, in a horizontally planted cylindrical sett, the sprouting will tend to originate more from the upper and lower quadrants of the sett than from the sides. The very important question that still remains unanswered is what determines the exact point on the tuber surface at which a sprouting locus will develop. Why does it not arise a few centimetres away from its actual location? There have been suggestions (Passam, personal communication) that the sites at which sprouting loci will form are predetermined. Alternatively, it could be that minor differences in the microclimate surrounding various points on the tuber surface cause the formation of sprouting loci to be favoured in some locations but not in others.

Temperature affects the sprouting of yams (Onwueme, 1975c). While sprouting occurs readily at 25°C and 30°C, it is considerably delayed at 35°C or 15°C. Since soil temperatures exceed 35°C for several hours nearly every day in many parts of the yam-producing tropics, this means that planted tubers may be exposed to supra-optimal temperatures which may inhibit or retard their sprouting. Further, it is known that on hot days the soil is hottest near the surface and progressively cooler at greater depths. Thus while the top part of a planted sett may be near the soil surface and exposed to a very high temperature, the lower part of the same sett may be several centimetres below the soil surface and therefore cooler. Actual field measurements (Onwueme, unpublished) have shown that the lower portions of some setts may be up to 8°C cooler than the top during the hottest part of the day. This may cause setts planted in hot seasons to sprout mostly from the lower, cooler, portions. Mulching and deep sett placement are two ways to alleviate the high-temperature problem. Mulching not only lowers the average temperature that the sett is exposed to, but it also reduces the temperature difference between the upper and lower portions of the sett. In addition, it seems advisable that setts which have the tuber skin only on one side should be planted with the skin downward to avoid the effects of excessively high temperatures.

Lack of water supply does not affect the rate of bud formation on the yam tuber, but the subsequent elongation of the bud is slowed by moisture stress. Intact tubers have long been known to sprout while in storage, or on a table. Also, setts planted in dry sawdust, dry soil, or dry paper reportedly sprout as readily as moistened setts (Onwueme, 1976). However, setts that were sprouted under dry conditions tended to produce several more sprouting loci than those sprouted in moist media. In addition, the buds produced by setts under dry conditions remained relatively unelongated unless moisture was supplied. Apparently the yam tuber, with its high moisture content, requires no further hydration for sprouting to occur. Moisture needed for the process is supplied endogenously.

The effect of physiological age of the planted tuber on subsequent tuber initiation has been discussed above. A similar effect pertains to tuber sprouting. Freshly harvested tubers cannot be made to sprout immediately. They go through a period of dormancy during which they cannot sprout (Campbell *et al.*, 1962a; Coursey, 1967), with the dormancy becoming progressively shorter after harvesting (Figure 14). As such, if tubers that were harvested during the same period are planted at different times, the earlier planting will require a very long time before it can sprout, while progressively later plantings require progressively shorter times to sprout (Onwueme, 1975a). Approximately six months after harvesting, the dormancy has disappeared completely, and budless setts planted after that time will require approximately the same (short) time to sprout.

Little is known of the mechanism of dormancy in the yam tuber. Campbell *et al.*, (1962b) have suggested that dormancy is associated with low levels of glutathione in the tuber, and that the glutathione level is high when the dormancy level is low. Others (Ireland *et al.*, 1981) suggest that batatasins may play a role in yam tuber and bulbul dormancy. Whatever the dormancy mechanism may be, many attempts have been made to break dormancy artificially, and thereby cause dormant tubers to sprout. Ethephon and 2-chloroethanol are substances which reportedly can break yam tuber dormancy. Gregory (1968) and Martin *et al.*, (1974b) were able to promote the sprouting of yam tubers by means of gamma radiation, conversely Adesuyi (1973) reported that gamma radiation inhibited yam sprouting.

Attempts have also been made to increase the level of dormancy in yam tubers in order to prevent their sprouting during prolonged storage. Campbell *et al.* (1962c), using the methyl ester of a-naphthalene-acetic acid (MENA), were able to retard sprouting in stored yam tubers. They concluded, however, that the treatment was unlikely to be of economic importance because tuber weight loss was not reduced, and the tubers became warty. Satoh (1971) found that foliarly applied maleic hydrazide on *D. batatas* retarded the sprouting of the subsequent harvest tubers, but this was not so for *D. rotundata* (IITA, 1971). Gibberellic acid has been tried as an inhibitor for sprouting (Martin *et al.*, 1974a); and gamma radiation has also been used to prolong the dormancy of yams in storage.

Attempts to manipulate yam dormancy are bound to continue. For effective year-round production to become a reality, commercially feasible methods must be found to break tuber dormancy, so that any tuber used as a planting material will sprout easily, irrespective of when it was harvested. Ability to prevent unwanted tuber sprouting during storage will also eliminate one of the major sources of dry matter loss.

The dormancy behaviour of the yam tuber raises some complicated questions concerning terminology in discussing yam production. Specifically, most phenological events, and instructions to farmers, have traditionally been stated in terms of number of days or weeks *after planting* (e.g. "apply fertilizer 3 months after planting"). However the wide variation in time from planting to sprouting (depending on the physiological age of the sett) makes the use of *time after planting* thoroughly ambiguous as a marker. To apply fertilizer at 3 months after planting to a field planted with long-stored setts, would find the plants far advanced in canopy formation; the same recommendation for a field planted with freshly-harvested tubers would mean applying fertilizer to the crop before emergence. Similarly, a report that "tuber formation usually starts at 10 weeks after planting" would be equally misleading and ambiguous. Onwueme (1975a) reports experimental data in which non-head setts planted one month after harvesting required 108 days after planting to sprout, while those planted 7.5 months after harvesting sprouted in only 20 days.

It is suggested, therefore, that the time of planting should be replaced by the time of *emergence* (or sprouting) as the cardinal time in yam growth and production discussions. This suggestion is based on the fact that, once sprouting and emergence have occurred, no other period of prolonged inactivity normally occurs in the plant's growth cycle until the vine dies back. Most field phenological events and recommendations relating to yams should therefore be stated in terms of weeks or days *after emergence*. Finally, in view of the dependence of sprouting on the time the tuber was harvested, it is always helpful in reporting yam experiments to state the time when the tuber used for planting was harvested.

Chapter 9

CULTIVATION OF YAMS

9.1 CLEARING

For most crops in most places, the clearing of land on which to plant is a minor task; but in the forested tropical areas where yams are grown, the initial clearing of the land looms as a major operation. In traditional subsistence agriculture where bush-fallow (shifting cultivation) is practised, the land is cleared, farmed for a year or two, and then allowed to return to bush while another area is cleared for farming. As such, the clearing of land is a repetitive event in traditional agriculture, occurring yearly as old plots are abandoned and bush is cleared for new ones. Where the pressure on land, or modernization, has forced the adoption of continuous cropping of the piece of land, clearing is a major task only in the first year when the land must be reclaimed from bush. In subsequent years, clearing is never a major task.

9.2 TILLAGE AND SEED-BED PREPARATION

Root and tuber crops in general require a loose soil in which their tubers can grow with little hindrance. This requirement is even more critical for yam than for many other tuber crops. The reason for this seems to lie in the manner in which the tubers form and penetrate the soil. Many tuber crops (e.g. cassava, Irish potato) initially form relatively thin roots or stolons which first penetrate the soil, and later begin to enlarge to form the tuber. For most yams, on the other hand, tuber formation is not preceded by any stolon-like structure, so that it is the relatively blunt tail-end of the tuber that must accomplish penetration through the soil. For this reason, planting of yam is invariably preceded by tillage operations with the aim of loosening the soil. This is true even in traditional yam production.

9.2.1 **Mounding**

Planting of yams on mounds is the most common practice in traditional yam production. Essentially, the top soil is gathered into more or less conical heaps at various points in the field, using various kinds of hoes. The size of each mound (heap), the mean distance between mounds, and the number of yam stands planted on each mound vary from place to place; but in general, the bigger the mound, the greater the distance between mounds, and the greater the number of setts that may be planted on the mound. In some parts of south-eastern Nigeria, mounds may attain heights of up to 1 m, be separated by distances of over 3 m, and have up to six setts planted at various points on the sloping sides of each mound. In most yam-growing regions, however, smaller mounds of about 50 cm in height are more common, and only one or two setts are planted on each mound. Other crops (e.g. maize, okra, melon) are invariably planted in the spaces between mounds, so that the exact spacing between mounds depends on if, and how much, intercropping is envisaged.

The mounds, particularly the high ones, provide the ultimate in a loose seed-bed for tuber penetration. As such, the largest yields of tuber per plant, and the most uniformly shaped tubers, are obtainable from mound plantings. Since the soil is loose, the tuber is able to penetrate without much hindrance. A second factor which may contribute to high yields of mound-grown yams is that the process of mound-making collects the rich top soil of the entire field into heaps on which the yam is planted. As such, the entire depth of the mound consists of fertile top soil, rich in organic matter, and most of the yam roots are in this zone. In the normal unmounded soil, only the top few centimetres of the rooting zone would have such fertility. A third advantage of mounding is that it facilitates harvesting. Since the soil is loose, soil excavation for harvesting is relatively easy. Finally, mounding may serve a useful purpose in the water management of some fields. In soils where the water table is high, the mounds serve to keep most of the roots above the water table. In addition, the intricate network of furrows between the mounds may be utilized to irrigate the field.

Notwithstanding its advantages for the plant, mounding has the major disadvantage of being laborious and not easily mechanizable. It is mainly for this reason that yam-growing on mounds has been restricted to traditional agriculture. The situation is expected to remain the same, and yam production by future generations will most probably not rely on mounds. If future market preferences are not particular about tuber size and shape, some of the major advantages of mound planting will become immaterial.

9.2.2 Flat Planting (Holes)

A second common method of yam planting is to plant on the flat (in holes) on ploughed or unploughed fields. A relatively narrow blade hoe is used to make small holes in the newly cleared or freshly-harrowed field. Each hole is about 30 x 30 x 20 cm, and the spacing of the holes depends on how much intercropping is envisaged. Only one yam sett is planted in each hole. Yam planting in holes is frequently done without ploughing, an example of the traditional practice of minimum tillage. Apart from the spots where the holes are dug, the entire field is untilled. This probably has advantages in maintaining a good physical structure of the soil in general, as well as conserving labour.

Planting on the flat results in low yields (Lal and Hahn, 1973; Lyonga *et al.*, 1973), the mean yields per plant being lower than for mound or ridge plantings. Because the loose layer is only a few centimetres deep, heaving is often a problem, and quite often, the tail-end of the tuber becomes misshapen and irregular as it attempts to penetrate the unploughed soil layer below. Harvesting is difficult, and may result in considerable tuber damage.

A practice which may improve the performance of flat-planted yams is that of subsoiling or very deep ploughing. This would loosen up the soil to a greater depth than usual, and therefore alleviate the problems associated with the tuber reaching the unploughed hard-pan. A slight modification of flat planting is the practice of 'trenching'. After ploughing and harrowing, shallow trenches running the length of the field are dug with machines. The yam setts are put in the trenches, which are then covered up.

9.2.3 Ridging

In improved agriculture where some degree of mechanization has occurred, yam is generally planted on ridges. Bush clearing is followed by ploughing to loosen up the soil, and harrowing to break up the clods and improve the physical condition of the soil. Ploughing and harrowing also serve to incorporate crop residues and other organic matter into the soil. It is after harrowing that the ridges are made using a tractor-drawn ridger. The ridges are commonly spaced 1-1.2 m apart. The higher and broader the ridge, the better. A high ridge provides ample depth of loose, fertile soil for tuber and root penetration, and a high, broad ridge is less readily washed away by rain during the course of the season. Where traditional farmers plant yam on ridges, the ridges are commonly made by hand, without prior ploughing or harrowing.

After the ridges have been made, the actual planting of the setts on the ridge is carried out by opening up the soil at the crest of the ridge with a hoe, inserting the sett about 10 cm deep, and covering it with soil.

Planting on ridges has some of the same advantages as planting on mounds. In addition, it has the advantage that ridge-making is completely mechanized, and that, on slopes, ridging along the contour can help in erosion control. One major difficulty often encountered in ridge plantings is that, during the course of the season, the rains tend to wash soil away from the ridge-tops, thereby decreasing the height of the ridges. The washing may progress to an extent where the tuber growing within the soil becomes exposed. Such exposed tubers are generally unpalatable, develop chlorophyll in their subsurface layers, and are easy prey for rodents and other pests. Sometimes too, the tuber of a yam growing on a ridge will penetrate downward through the loose soil of the ridge until it encounters the harder soil at the base of the ridge. Further growth of the tuber will cause it to exert upward pressure ('heaving') rather than to penetrate the harder soil below. In such a situation, the top portions of the tuber may become exposed even if no appreciable soil wash has occurred. The consequences of such exposure are similar to those caused by soil wash. To avoid the above it it necesary to ensure that the ridges are high and broad, and that the sett is planted deep enough at the crest of the ridge. Constant building up of the ridges by scooping soil from the furrows with a hoe and placing this soil on the ridges will avert this. This procedure, called 'earthing up', is done routinely during hoe-weeding operations.

It seems that the growing of yams on ridges will continue to increase in importance, and may become the main method of production in the future. The fact that ridge-making can be done mechanically means that very large acreages can be cultivated. Moreover, 'heaving' and tuber exposure, the two main difficulties in ridge-grown yams, will become less important if, as expected, future production is geared towards obtaining smaller tubers.

Occasionally, yams are planted on raised beds which are essentially very broad ridges with flat tops. Such beds are often made with hand tools. The acreages grown by this method have remained limited, and probably will continue to be so.

9.3 PLANTING MATERIAL

9.3.1 **Sett weight**

The greater the weight of the sett used to establish a yam plant, the greater the weight of tuber produced by that plant. This relationship between sett weight and yield has been repeatedly confirmed in various experiments (Miege, 1957; Onwueme, 1972; Lyonga *et al.*, 1973; Nwoke *et al.*, 1973). It appears that the following reasons may account for the relationship.

(1) Large setts sprout more rapidly than small setts (Onwueme, 1973), and as such are able to establish themselves and grow more quickly.

(2) Large setts produce more sprouting loci and more sprouts per sett than smaller setts (Onwueme, 1973). This means that in cases where a sprout may be damaged during emergence, the large sett has a greater number of alternative shoots that can take over as the main shoot. As a result the percentage field emergence is greater for large sett plantings (Onwueme, 1972); the greater number of plants surviving per hectare contributes to the greater yield realized.

(3) The large sett gives rise to a more vigorous plant than the small sett, even if both sprouted and emerged at the same time (Onwueme, 1972; Enyi, 1973; Nwoke *et al.*, 1973). The vine diameter, number of leaves per stand, and leaf area per stand are greater for the large-sett planting than for the small-sett planting. Apparently the greater amount of food material initially available to the large-sett plant enables it to form more elaborate and vigorous shoot structures. These structures, particularly the greater leaf area produced, in turn result in the production of a larger tuber. According to Nwoke *et al.* (1973), the main effect of large sett size is to produce a vigorous initial growth of root, vine, and leaves which give the plant an advantage that lasts throughout the growing season.

(4) The large sett has more food material which can be translocated directly to the new tuber. Onwueme (1975b) has shown that food material present in a sett can be transferred directly into the new tuber. Since the large sett has more food material available for this transfer than the small sett, its potential direct contribution to the new tuber is greater. Even in situations where partial sett rotting occurs, the large sett is likely to have a greater amount of unrotted material available for translocation to the new tuber.

(5) Tuber initiation occurs earlier, and tuber bulking proceeds faster, in plants established from large setts.

A greater yield of tuber is not the only characteristic associated with large-sett plantings when compared with small-sett ones. The difference in general plant size has already been mentioned. In addition, plants from large setts produce a greater number of tubers per stand than plants from small setts (Onwueme, 1972). This is probably an indirect consequence of the greater number of sprouts produced by large setts. When a single sett produces two or three different sprouts which emerge and continue to grow, each sprout develops its own root system and behaves as a separate plant. Soon, the sett material connecting the sprouts rots away so that the separation of sprouts is completed. The two or three plants resulting from the separate sprouts will grow, and each will produce its own tuber. As such, two or three tubers are produced at the stand where only one sett was planted originally. The multiple plants that result from a single large sett are each smaller than if the same sett had produced a single plant; similarly the multiple tubers that result are each commensurately smaller than that resulting if the sett had produced a single tuber. Two or three different sprouts growing to maturity from a single large sett therefore behave as if two or three smaller setts had been planted on the same spot.

In commercial yam production, setts weighing 150-300 g should be used for planting. Even though larger setts may produce bigger yields per stand, the yield per unit weight of planting material (i.e. the *multiplication ratio*) tends to decrease as sett weight increases (Onwueme, 1978). For this reason, setts heavier than 300 g should not normally be used for commercial production. For some traditional farmers who routinely plant setts weighing up to 450 g, the return per unit weight of planting material may be very low. Larger sett weights ranging up to 4.5 kg have been used for planting (Coursey, 1967), but such plantings are usually made for specialist production of very large tubers, rather than for routine commercial propagation. The lower limit of sett weight used for commercial production is determined by the fact that very small setts tend to rot readily, emerge poorly, and produce very small tubers. Even though yam plants can grow from sprouted pieces as little as 5 g (Onwueme, unpublished), commercial production of ware yams utilizes setts in the 150 g range or heavier.

9.3.2 Sett type

Yam is commercially propagated by means of the tuber. The tuber pieces used for planting may be small whole tubers, or tuber-pieces derived from a large tuber that has been subdivided into smaller pieces. When such subdivision is done, then the setts may be derived from the head, middle or tail region of the original tuber, and are referred to as *heads*, *middles* or *tails*, respectively.

Two important factors govern the appropriateness of a sett as planting material:
(1) the readiness with which it will sprout, and
(2) how prone it is to rotting or degradation after planting.
The relative preference of wholes, heads, middles, and tails will be examined in the light of these factors.

It has already been mentioned that when the dormancy of the yam tuber begins to decrease, sprouts appear in the head region and nowhere else on the tuber as long as it remains intact. It follows then that, if the tuber has been stored long enough, setts derived from the head region will have already formed sprouts. Setts derived from other parts of the tuber have no sprouts, and must spend some of the time after planting differentiating sprouts. Even if tuber storage time has been short and the head region has no sprout at planting time, it has been shown (Onwueme, 1973) that the head sett differentiates a sprout more readily after planting than do non-head setts. The overall result, therefore, is that setts derived from the head region sprout and emerge more rapidly than setts from other parts of the tuber. On this basis, heads and whole tubers would be preferable to middles and tails.

The intact yam tuber is normally covered by a layer of cork which gives protection against the ingress of microbial rotting agents. When the tuber is cut in the process of sett preparation, the integrity of the protective layer is broken, and the cut surfaces are weak areas through which rotting can begin. In general, the greater the area of cut surface on the sett, the greater its tendency to rot after planting. Indeed, the greater the *skin:cut surface ratio*, the less prone the sett is to rotting. Moreover, sprouting loci can only form on skin areas, and not on cut surfaces On this basis, the whole tubers, with their protective layer intact, are superior as planting material to setts cut from larger tubers.

The best planting material for yam is therefore the small whole tuber which, as it has a head region, will sprout readily, and because it has no cut surfaces, is least prone to rotting. The next best are heads, which sprout readily, followed by tails, and middles.

9.3.3 The yam minisett technique - planting with whole tubers

The realization that the whole tuber was the best planting material for yam has long led many generations of farmers to deliberately produce whole tubers ("seed yams") for sale to other farmers as planting material. This they did by planting very small cut tuber pieces which would, at harvest, yield wholes of plantable size (200-500 g). However, the procedure suffered considerably from post-planting rotting and deterioration of the cut pieces. The *minisett technique* (Okoli, Igbokwe, Ene, & Nwokoye, 1982) was developed to solve this problem. As originally reported, it involved the cutting of larger yam tubers into 25 g setts ("minisetts"), and dusting them with an insecticide/fungicide formulation. The treated minisetts were then planted in the field, or pre-sprouted in germination chambers for some weeks before field planting. Spacing in the field was 25 cm on ridges that were 100 cm apart, giving a population of 40,000 plants/hectare instead of the conventional 10,000 plants/hectare. Various modifications of the technique have included growing the plants using plastic mulches and without staking (IITA, 1985), as well as attempts to further reduce the weight of the minisett.

The main advances represented by the minisett technique are the ability to use much smaller setts than was hitherto possible, the identification of an effective insecticide/fungicide combination for protecting the planted setts, and the planting of the setts at high density thereby creating a situation of intensive cultivation (Onwueme, 1989). It also sets the stage for the development of a genuine "seed yam" industry for generating yam planting material. For these reasons, the minisett technique has been enthusiastically adopted by farmers, especially in West Africa. However, certain problems still remain. First, the technique is very crucially dependent on the efficacy of the insecticide/fungicide combination. The original insecticide recommended (Aldrex) has since been found to be environmentally unacceptable. Readily-available efficacious substitutes have been hard to come by. Wood ash has been tried as a substitute, but its reported effectiveness is variable. For the minisett technique to fully take hold, it is necessary to find a pesticide combination that is safe, efficacious, available and economical. These same criteria must be met by such inputs as plastic mulches within the context of traditional farmers and developing countries. Secondly, the "seed yam" resulting from the minisett technique are still very expensive. This is because the process is labour intensive, in addition to being capital intensive. Thirdly, there is some debate about the entire philosophy of the minisett technique. It entails going through one season to produce "seed yam" then going through another season to produce ware yams. The cumulative labour and capital costs ensure that the ware yams ultimately produced are very expensive. The minisett technique became necessary in the first place because "seed yams" sprout more readily and resist post-planting deterioration better than conventional setts. If conventional setts can be made to acquire these two attributes, then it would no longer be necessary to go through the minisett technique and the two-season cycle which it imposes. Some efforts in this direction include the dry pre-sprouting of conventional setts, while protecting them from decay and pests (Onwueme, 1976, 1977; Atu & Onwueme, 1991).

Another future solution to the two-season problem might be to simply forget the second season, and market the "seed yam" (which weigh 200-500 g) resulting from the first season for direct human consumption. The problem for now lies in the preference for large tubers, especially in the West African yam zone. When this preference is eventually broken, the minisett technique may inadvertently find utility as a method for producing yams for direct human consumption. The export trade in yam (*D. cayanensis*), in Jamaica is based on the production of "seed yam" directly from minisetts. Research to improve the uniformity in sprouting of minisetts is essential to reduce variations in "seed yam" production.

9.3.4 Planting with conventional setts (from previous season's harvest)

Most present-day yam farmers simply depend on their previous season's harvest to supply the planting material for the following season. A portion of the previous season's harvest of ware yams, and nearly all of its small unmarketable tubers, are set aside as planting material for the next season. The ware yams are cut into pieces for use as setts while the small tubers are planted whole.

The cutting of the large tuber into setts is done 1-2 days before the envisaged date of planting. This time interval allows the cut surface to heal over before the sett is placed in the ground. Tubers selected for planting material should be as healthy as possible. The skin may be broken slightly to check if the subsurface meristematic layer, from which the sprout will differentiate, is healthy. Nematodes sometimes damage this layer and cause it to be brown, even though signs of damage may be absent on the tuber surface or in the deeper starchy portion. Tubers with browned meristematic layers should not be used for planting, neither should tubers that are warty or visibly rotted.

If the tuber being cut possesses a large head region, then this region should be divided longitudinally so that two or more different setts have portions of the head region, and will therefore sprout rapidly. It is obvious that each sett must have some portion of the tuber skin, since sprouting can only occur from the meristematic layer just beneath the skin. Indeed, the greater the amount of tuber skin on each sett, the better. The *skin:cut surface ratio* should be as high as possible.

After the cut setts have been produced, they should be handled carefully to avoid damage and infection. Traditional farmers sometimes smear the cut surfaces with wood ash which presumably exerts some effect against rotting. Dipping in pesticidal solutions of Benlate, Captan, limewash, or Bordeaux mixture also offers some protection. During the one or two days between sett cutting and planting, the setts should not be stored in a humid environment which might encourage microbial rotting. If the cut surfaces of the setts are placed face-down, there is a local build-up of humidity around the surface so that fungal infection occurs readily. It is therefore best to store the setts in a well-aerated environment with the cut surfaces facing upward.

9.3.5 Pre-sprouting of yam

It has been mentioned earlier that, during storage, a yam tuber will develop sprouts at the head region; no sprouts develop in the middle and tail regions, as long as the tuber remains intact. Apparently, the sprout forming on the head region exerts some apical dominance which suppresses the formation of sprouts on the other parts of the tuber. If the tuber is cut into setts and planted, the tails and middles are liberated from this dominance and commence to differentiate sprouts. However, they require several weeks to do this. Their emergence is not only delayed, but lags several weeks behind that of the head sett, resulting in a low uniformity of emergence for the field as a whole (Onwueme, 1984).

One way to circumvent this problem is to cut the tubers and attempt to produce a sprout on even the middles and tails before planting in the field. A practice to this effect exists among some traditional yam farmers. The tubers are cut into setts during the dry season, about three months before the projected time of planting in the field. They are then buried as a group in shallow ditches about 15 cm deep. Placement in the ditches is such that the setts are in one layer and no sett is placed on top of another. The setts are then covered over with soil. No watering is done, but shade is provided by placing dead plant material on top of the covered ditches. After about two and a half months the setts are checked to see if appreciable sprouting has occurred. Even middles and tails should have developed sprouts by this time. To prevent the sprouts from becoming too long, the setts are removed from the ditches and placed on platforms in a shady place on the farm. Sprouts that have become very long, usually on heads, are cut back. When it is time to plant, often with the early rains, the sprouted setts are then planted in the field. This method amounts to sprouting the setts in a nursery before planting them in the field.

The main advantage of pre-sprouting the setts before planting is that the emergence characteristics are improved. If the freshly cut setts are planted directly in the field, there is no way for unsproutable ones to be detected and discarded. The process of pre-sprouting the setts allows the farmer to plant only setts of proven sprouting ability, so that unsproutable ones are sorted out and discarded. As a result, the percentage emergence in the field is much higher than when freshly cut setts are planted. In addition, emergence occurs rapidly and uniformly after planting (Onwueme, 1977a), unlike planting with unsprouted setts where there is a wide disparity (one month or more) between early and late emergers. Since every sett has a sprout on it, middles and tails emerge as rapidly as heads, so that the plants are at approximately the same stage of development throughout the season. The main difficulty with this method of pre-sprouting yam setts is that usually a very high percentage of the setts are rotted during the period in the ditch. A loss of over one-third of the buried setts is not uncommon (Onwueme, 1977a). This is probably so for two reasons. Firstly, since the ditches are outdoors, their environment is not regulated, and the setts are potentially subject to rains, high humidity, and high temperature, which may promote rotting. Secondly, since the setts are buried *en masse,* any one of them which was infected at the onset has an ideal opportunity to spread the infection to all the other setts. The high humidity and possible rainfall contribute to the creation of ideal conditions for the spread of rot from any infected sett. This does not occur if the freshly cut setts are planted directly in the field. An occasional infected sett may rot thoroughly in its hole without spreading the infection to even its closest neighbour which is some distance away.

Many of the sprouted setts produced after pre-sprouting may be partially rotted or carry rot-causing infection when they are planted in the field. As a result, the vigour of the resulting plants is considerably reduced, and yields are adversely affected. The likelihood of rotting during pre-sprouting can be reduced by cutting the setts according to the sanitary precautions outlined for setts to be planted directly in the field. Allowing the cut surfaces to heal for a day or two before burying may also help the situation. Many traditional yam farmers who pre-sprout their setts do not rely exclusively on this method. They usually pre-sprout part of their planting material, and keep the rest to be cut at planting time. This is necessary because they are uncertain as to how much rotting will have occurred in the ditches. One further difficulty encountered in pre-sprouting setts in field ditches is that many setts, particularly heads, may develop very long sprouts several weeks before the proposed time of field planting. If left unchecked, such setts will produce elaborate root systems in the ditch before it is time to move them to the platforms. One solution is to cut back long vines before or at the time when they are unearthed and taken to the platforms.

A new method intended to circumvent some of the difficulties of pre-sprouting setts in the field has been suggested by Onwueme (1976, 1977a, Atu & Onwueme, 1991).

It was found that even middle and tail yam setts did not require external water in order to sprout (see Figure 15). Hence sprouting could occur in dry soil, dry sawdust, dry shredded newsprint, or even on the shelf. Sprout formation in these dry conditions was as rapid as in setts planted in moist media, but the sprout formed remained short and relatively unelongated. Thus, it was sprout elongation, not its formation, that was mainly dependent on the external water supply. It is therefore possible to cut the tubers into setts months before planting, let them sprout indoors on shelves or in bins containing dry material, and then plant the sprouted setts in the field at planting time. This method has three advantages over pre-sprouting in the field:

(1) Pre-sprouting can be done indoors or in containers, so that complete control of the environment is possible.

(2) It affords an opportunity for periodic examination of the setts during pre-sprouting; the progress of sprouting can be observed, and any decaying setts can be isolated from the rest by being discarded.

(3) Sprouts formed under dry conditions tend to remain short and manageable until planted in the field, unlike the lengthy sprouts that may sometimes result during pre-sprouting in ditches.

The major difficulties in dry pre-sprouting are rotting and insect attack. Fungal rots are a particular problem, which can be aggravated by burrowing insects infesting the setts. As with the minisett technique, fungicides and insecticides must be found which will minimize the incidence of rots and insect attack on the setts. It is also important to avoid desiccating the setts; they may not need water, but they should not lose that which they already have.

Pre-sprouting of yam setts, especially indoors in dry conditions, is a practice that holds promise for the future, if the problem of rotting can be solved. Among other things, it will shorten the time from field planting to harvesting, which may allow a short season crop or a fallow period to precede or follow yam in the same season. It also should provide a viable alternative to the minisett technique and the deliberate production of "seed yam", already discussed.

9.3.6 Exclusive use of heads

If a farmer were to plant only heads, he would get as rapid an emergence as with "seed yam", and more rapid than middles and tails. The emergence would also be more uniform than with the present widespread practice of planting a mixture of heads, middles, and tails. This would also remove the need for pre-sprouting, since heads either have sprouts on them, or develop sprouts very rapidly after planting. The main problem lies in the logistics of the farmer getting enough heads, since consumers may resist buying tubers from which the farmer has removed the heads. It may also be difficult to prevent rotting at the cut surfaces where heads were severed.

9.3.7 Planting with bulbuls

Many yams normally grown for their underground tuber also produce bulbuls aerially. Attempts have been made to conserve the underground tuber for consumption while using the bulbul for planting (Onwueme, 1985). Surprisingly, the larger bulbuls resulted in lower tuber yields than smaller ones. For *D. bulbifera* which is normally grown for the bulbuls, commercial propagation by means of bulbuls is quite common.

9.4 TIME OF PLANTING

Current practice in yam production is that yams are planted either in the dry season or at the onset of the rainy season. Depending on the locality, the calendar dates of these operations may vary.

For dry-season planting, land preparation begins just before the rainy season ends, and before the soil has become dry and difficult to work. The setts are then planted, but because these setts were harvested only a month or two earlier, they do not begin to sprout immediately. Instead they pass their dormant period in the soil, and it takes about three months after planting before large-scale sprouting is observed.

For rainy-season planting, land preparation may be done early in the dry season, or it may be postponed until just before the rains begin. However, the setts are not planted until the rainy season begins. Such setts, because they have been stored through the dry season, will sprout readily, usually in a month or so.

The dry-season planting has the advantages that it gives an earlier harvest, and that land preparation is easier at the onset of the dry season. On the other hand, rainy-season planting has several advantages over dry season planting:

(1) The rainy-season planting requires a much shorter time from planting to harvesting, than the dry-season planting. The extra time that the dry-season planting needs before emergence is a wasteful occupancy of the field, especially since it does not necessarily result in higher yields. That time could well be spent growing some other crop.

(2) The dry-season planting follows too closely on the heels of harvesting of the previous crop. Indeed, many farmers are still busy harvesting their yams till the second half of the dry season. For them to have to direct some of their precious labour to dry-season planting at this time is a real handicap. On the other hand, harvesting of the previous crop is completed by the time the rainy-season planting is due. Fortunately too, yams can, and should, be planted much earlier in the rainy season than most other crops. As a result, the time of rainy-season planting is a time when labour demand for other uses on the farm is low.

(3) Where the same piece of land is used for yam in successive years, the period between harvesting and rainy-season planting allows the land some fallow period each year. However, if dry-season planting is practised, the new crop must be put in almost immediately after the previous crop is removed. Not only is the land not fallowed, but the entire process requires a considerable rush.

(4) The emergence of the dry-season planting is spread over a much longer time than that of the rainy-season planting (Onwueme, 1977a). As such, the rainy-season planting results in less disparity between the stages of development of plants in the same field.

(5) The period from planting till emergence for the dry-season planting is usually the driest and hottest season of the year. The setts do not perform well unless they have been heavily mulched, and this adds to the cost of production. For the rainy-season planting, lighter mulching will suffice.

On the whole, therefore, it is preferable to plant at the onset of the rainy season. It should be emphasized that rainy-season planting should be done as early as possible. Planting should be done when the rains are still irregular, so that by the time the rains are regular, emergence is already occurring. In the northern forest zone of Nigeria, February or early-March plantings are recommended, even though the rains do not become regular until late March or April. Once the rainy season has started, the later the planting the lower the yields obtainable (Chinwuba, 1971; Lal and Hahn, 1973). The low yield of late-planted yams is due, in part, to the short growing season available to the plants before the dry season forces them to die back. It is also due partly to the fact that the tubers used for late plantings have been stored for so long that they form tubers before appreciable leaf formation has occurred. As discussed earlier, such tubers cannot grow very big because the leaf area supplying them is relatively small.

9.5 SETT PLACEMENT

9.5.1 Spacing

Yams are generally planted at a spacing of about 1 m on rows that are 1 m apart. Wider or narrower spacings may be used, depending on the sett size and cultivar. The bigger the sett, the wider the spacing. It has also been suggested (USDA, 1972) that wider spacing should be used on heavy soils. As has already been mentioned, spacing in traditional yam production is variable, depending on how much intercropping is envisaged. Onwueme and Fadayomi (1980) have demonstrated that a close spacing of 1m x 0.5m can be advantageous for weed control, especially if the crop is grown without stakes.

9.5.2. Depth of sett placement

Yams should be planted such that the top part of the sett is about 10 cm below the soil surface. This deep placement arises from the need to place the sett away from the hotter, drier surface of the soil and into the cooler, more moist region beneath. The deep placement presents no difficulty of penetration for the average yam sett. The ability of the yam sett to emerge from such depths is because of the large amount of food stored in the sett. Emergence from shallow depths is not particularly advantageous since, at any rate, the shoot will usually remain leafless for a long time after emergence.

9.5.3 Sett orientation

It is not clear whether the orientation of the sett when it is planted affects its emergence and future growth. Good viable setts will sprout and emerge irrespective of their orientation. However, it is advisable, especially in long setts, not to place the head downward since this creates a greater distance for the sprout to travel before it can emerge.

Under hot conditions, sett placement may be of some significance, especially if the plot is not mulched. As previously stated, the lower portion of a sett may be up to 8°C cooler than the upper portion. Under hot conditions, therefore, the lower part of the sett may be more likely to produce a sprout than the hot, upper portion. Whether most sprouts under hot, field conditions originate from the lower side of the sett is not known. However, as a precaution, setts with skin on only one side should be planted with the skin downward if hot conditions are anticipated before emergence.

9.6 MULCHING

Soon after yam has been planted, it must be mulched in order to protect it from excessive heat and desiccation. This is particularly important because yam requires such a long time from planting to emergence, and because the periods immediately following planting are often very hot. Not only does mulching reduce the temperature attained within the seed-bed by several degrees, but it also reduces the temperature-difference between the upper and lower portions of a sett that has been planted.

The need for mulching is so critical in yam production that drastic reductions in yield occur if mulching is not done (Lal and Hahn, 1973; Lyonga *et al.*, 1973). Apparently, unmulched plots suffer from a reduced percentage emergence. The need for mulching is most critical in yam setts planted in the dry season. Because they spend a long, dry period in the soil before emerging, dry-season plantings usually show very low percentage emergence if the setts have not been protected by mulching. Rainy-season plantings also benefit from mulching, but it is less critical for them since they emerge more rapidly, and soil moisture is occasionally replenished by rains. The later the rainy-season planting is made, the less the need for mulching, since time to emergence continues to decrease while soil-moisture supply continues to increase. Dry-season and early rainy-season plantings must be mulched to obtain maximal yields, but planting done after the rainy season need not be mulched. Mulching may be of little advantage when yams are grown in milder climates, such as that of Trinidad (Brown, 1931).

The time to mulch yam plots is immediately after planting. It is preferable to carry it out on the day of planting; if this is not possible, it should be done on the following day. Mulch consisting of dried grass material is most commonly used. Care must be taken in selecting the source of the mulch. Mulches containing weed seeds, or pieces of vegetatively propagated weeds should be avoided. Also materials which harbour termites or are subject to termite attack should be avoided.

The mulch may be placed over the spots where the setts have been planted, or a continuous layer of mulch may be placed along the row. Where mounds are used, a layer of mulch is placed over the top of the mound, and some quantity of soil is placed over the mulch to prevent it from being blown away by wind.

9.7 STAKING

In most yam-producing areas, some form of staking is necessary to obtain maximum yields. The need for staking is more imperative in areas subject to cloudy periods and in humid forest zones than in the savanna regions. Staking is advantageous since it permits better leaf display, mutual shading of leaves is reduced and the photosynthetic capacity of the plant is greater. Staked plants therefore yield higher than unstaked ones. Staking also keeps the shoots away from the soil surface which may be hot early in the season, and moist later on. The former condition causes burning, while the latter may predispose the leaves to microbial diseases. Weeding and other farm operations are easier in a staked field than in one in which the vines trail on the ground at random. Thus it is often suggested that one of the reasons why unstaked plots yield so poorly is that weed control in them is difficult.

Staking is done about a month or so after emergence, and certainly before the vines begin to trail on the ground. Even though emergence may not occur all at once, it is preferable to stake the whole field in one operation rather than to stake only emerged plants, and return to stake newly emerged plants later.

There are several methods of yam staking in existence (Figure 16):

(1) *Individual staking*. In this method, a stout stake is placed vertically, and the yam plant is led to twine on it. One stake may be used for one yam stand, or the stake may be made to serve for two or three adjacent stands. In high mounds, where more than one stand grows on a mound, a single stout stake placed at the peak of the mound is often used for all the plants on that mound. Whether a single stake will serve one stand or a group of stands often depends on the sett size planted, which gives an indication of the expected shoot size. Large-sett plantings are more likely to produce large shoots, and therefore will need one stake per stand, than small-sett plantings. For individual staking to be effective, the stakes must be at least 2 m tall. Shorter stakes result in a reduction in yield (Waitt, 1960, 1961b; Chapman, 1965). In addition, the stake must be stout enough to withstand breakage or dislodging, especially when the yam foliage becomes heavy on it. Bamboo poles are ideal for this type of staking. In traditional yam cultivation, yam vines are sometimes made to climb up live shrubs and selected trees that were left on the plot during clearing. Similarly, in alley cropping, yams may be made to climb the trimmed live hedgerows. Sometimes, too, a tall cereal such as maize or guinea corn is interplanted with the yam. The yam vines are made to use the growing cereal plants for support. Even though the cereal is often harvested before the yam, this practice should be discouraged since the weakness of the cereal stalks results in large-scale lodging, and the yields of both yam and cereal are substantially reduced.

(2) *Pyramidal staking*. In this type of staking, each stand is supplied with a stake, but the stakes from three or four adjacent stands are slanted towards one another and tied together at the top to form a rough pyramidal structure. Each plant, after twining the

entire length of its own stake, will then intertwine with the other plants at the point of stake convergence. This type of staking has the advantage of being more stable, since the stakes in a pyramid tend to support one another. For this reason, the requirement that the stakes be stout is less crucial in this case than for individual staking. This is particularly significant for yam production in savanna areas where the availability of stout stakes is low. Stout stakes should be used if available, but even such relatively frail structures as the mid-rib of the oil-palm leaf may be used.

(3) *Trellising*. A crude trellis method of yam support has long been used by traditional yam farmers in the savanna areas of West Africa, e.g. the Oyo and Ilorin areas of Nigeria. The relative paucity of trees in these areas makes the use of conventional stakes uneconomical. Instead, the farmers plant their yams among the stubble of the previous season's crop of guinea corn (*Sorghum*). Each stand of the stubble is bent over to join up with the next plant in the row, which in turn joins with the next. A continuous low trellis is thus formed, and the yam plants twine along the trellis. In the Ogbahu district on the flood plains of the Niger, farmers combine individual staking with a network of ropes joining adjacent stakes and providing additional climbing space for the yams. A more elaborate trellis system for yam cultivation was developed in the West Indies. In this system, two very stout poles are placed at both ends of each row which runs the entire length of the field. A metal wire is strung between the poles at a height of about 2 m above ground. Intermediate poles at intervals of about 20 m provide additional support for the wire. Above each stand, a piece of string is hung down from the wire. When the plant emerges, it twines along the string until it reaches the wire. It then does the bulk of its twining along the wire. This trellis method has the advantages that the same material can be used for several years, and that, if mechanical harvesting is to be done, the trellis system can be easily dismantled.

Despite its advantages, staking is a very laborious aspect of yam production. It is estimated (Nwosu, 1975) that the average yam farmer spends about 60 person-days per hectare in procuring stakes and staking his yams. Worse still, staking is not only difficult to mechanize, but also stands in the way of mechanization of other aspects of yam production (e.g. harvesting, cultivation). In addition, conventional stakes are becoming scarcer and more costly as the forests that have yielded them for decades are converted to agricultural land. It is clear therefore that future yam production must find other methods of supporting yam plants. The West Indian trellis method is one answer in this direction, but even that still requires much labour and investment. It seems that the ultimate aim in yam production should be to grow the crop without any supports whatsoever, as is already being done in much of the savanna.

9.8 WEED CONTROL

It has been reported by Onochie (1974) that yams are particularly sensitive to competition from weeds during the early part of their growth. This report has been supported indirectly by Kasasian and Seeyave (1967) who state that beyond the first two or three months, subsequent weeding of yams in unnecessary. Whatever the situation, weeding is the major farm operation that engages the traditional farmer from the time he finishes staking until harvesting. Such a farmer may spend, during the season, up to 40-80 person-days per hectare on weeding alone; the entire farm is weeded three or four times during this period.

In traditional yam production, and even in some partly mechanized farms, weeds are controlled by hoes. Quite often, the short-handled hoe is used, but the long-handled (Indian) hoe is preferable since it eliminates excessive stooping during weeding operations. The general practice is to start the weeding from one part of the field, and to continue on successive days until the whole field has been weeded. If the field is excessively large, the first-weeded portions may again be in need of weeding. It is probable that the long time required to weed a whole farm is one of the major restrictions on farm size in traditional yam production. The mechanical weeding (cultivation) of yam plots is extremely rare, probably because the growth habit of the plant, and the need for staking, make it difficult to operate machinery through established fields. Also the shallowness of the root system dictates that surface weeding must be done with care.

The use of herbicides for weed control in yams has been widely reported. Since weed interference is most critical during the first three months after emergence, the usual approach has been to apply a selective herbicide just before yam emergence and in this way, keep weeds under control for the first few months after emergence. Weeds appearing late in the season cause little yield depression, and are either ignored or pulled by hand. Herbicides that have been found effective include diuron, ametryne, or linuron at approximately 3kg of active ingredient per hectare (IITA, 1972; Onwueme & Fadayomi, 1980). Close spacing of the yam crop can also contribute to weed suppression later in the season.

9.9 FERTILIZING

Like any other crop, the response of yams to fertilizer application depends on the fertility of the soil, as well as the species and cultivar in question. In general, yams respond well to nitrogen and potassium fertilization. However, results to date indicate that their response to phosphorus is slight (Coursey, 1967; Lyonga *et al.*, 1973; Umanah, 1973). This is partly because phosphorus is removed very efficiently from the soil by yams and is seldom a limiting factor (USDA, 1974a, 1974b) and partly because many soils used for yam production are naturally rich in phosphorus. In addition, mycorrhizae associated with yam roots facilitate the absorption of phosphorus. For these reasons, many fertilizer recommendations tend to ignore phosphorus almost completely. On the other hand, formulations of 11-11-13 are in use in the West Indies (USDA, 1974a, 1974b). A formulation of 10-10-20 is recommended for south-western Nigeria (Ojo, 1969), and one of 12-12-18 for south-eastern Nigeria (Mann, 1963). The recommended quantities of these fertilizers also varies. In Trinidad, 200 kg of ammonium sulphate per hectare or 400 kg of 11-11-13 compound fertilizer are recommended (USDA, 1974a, 1974b). In Nigeria, recommendations range from 125-250 kg/ha of ammonium sulphate or compound fertilizer. Generally, yams are sensitive to chloride, and this ion should be avoided in fertilizer recommendations. The use of slow-release urea fertilizers is being investigated in many yam-growing areas. Organic manures and composts may also be applied as fertilizer to yam plots.

Fertilizer application to yam is most beneficial if available at the time when the plant changes from dependence on the sett to true autotrophy. It is therefore best to apply fertilizer to yam at about one month after emergence. At this time, the root system is extensive enough to absorb and utilize the fertilizer, while active shoot expansion is just starting. Fertilization at this time, especially with nitrogen, enables the plant to develop as large a leaf area as possible, so that when tuber initiation occurs there is sufficient photosynthetic area to make the tuber grow rapidly. For example, Chapman (1965) found that ammonium sulphate applied at planting decreased the yield, but when applied three months after planting, it increased the yield by increasing the leaf area duration. It appears that potassium is particularly needed during tuberization (USDA, 1974a) so that it, too, should be amply available at this time.

The exact time when the fertilizer should be applied depends on the kind of fertilizer. Unfortunately, owing to the nature of the tropical soils and the heavy rains in many of the areas, many nitrogen and potassium fertilizers tend to leach easily from the soil and cannot remain in the rooting zone for a long time after application. Moreover, the shallowness of the yam root system means that even the slightest degree of leaching places the fertilizer out of reach of the roots. For this reason it is generally recommended that fertilizer application be split; the first application is made about one month after emergence, and the second is made about 7-9 weeks later when tuber bulking is in progress. If, however, leaching is not a major factor, as when slow-release urea or organic manures are used, then the fertilizer could be applied at, or immediately after, planting since it will be available when needed by the crop.

The mode of application of the fertilizer depends on the kind of land-tillage practice that has been used. If mounds have been used, the fertilizer could be applied in a spot or band about 15 cm from the yam plant. If ridges or flat planting are used, then it is best to apply the fertilizer in a continuous band along the row, about 10 cm away from the plants.

Even though fertilizer application is beneficial to yam production, its use in traditional agriculture is quite limited. As yams are grown on land that has been fallowed for some years, many traditional farmers obtain reasonable yields without using fertilizers, and therefore feel no need for it. However, as land scarcity causes the fallow period to become shorter, yields obtainable without fertilizer will continue to decrease, and this situation will encourage the traditional farmers to use fertilizer on their yams. Another factor which has limited fertilizer use is the widespread belief that fertilizers, especially potassium ones, cause the resulting tubers to deteriorate rapidly during storage. However, Umanah (1973) could not observe any such predisposition of fertilized yam.

9.10 CROPPING SYSTEMS FOR PRODUCING YAMS

Yam is a crop which requires relatively high soil fertility. At the same time, the West African yam belt, which accounts for over 90% of world yam production, is also ecologically suited for cassava production. This means that both crops are very frequently found in association, either in relay intercropping or in mixed intercropping. In much of the yam-growing zone, shifting cultivation is also practised. Usually, yam comes shortly after the land has been cleared from fallow, so it can utilize the high fertility of the soil at this time.

The section on cassava cropping systems has already described a relay system involving maize/yams/vegetables/ cassava as is applicable to the forest and moist savanna zones of Nigeria. Similarly, intercropping involving yam and cassava has been mentioned as occurring in Colombia and Nicaragua. In the drier savanna zone of Nigeria, Diehl (1982) has reported a two-year rotation involving yams. The yams are planted a few weeks before the onset of the rains in March, and allowed to grow as a sole crop till about July. Then millet and yam beans are introduced. Yam harvesting occurs from October to February then, as the rains come again, an intercrop of maize/cowpea/ sorghum is planted. Bush fallow then follows. Indeed some parts of the guinea savanna reverse this sequence by planting sorghum/millet and cowpea the first year. In the second year, the left-over stalks of the cereals are bent over to serve as climbing trellises for the yam crop. Intercrops of yams with maize and vegetables are quite common in Guadeloupe and other parts of the Caribbean.

The use of live stakes for yam production also occurs in other contexts. In some parts of southeastern Nigeria, the fallow period is not just one for random regrowth of the bush. Instead there is a deliberate practice of planting and tending certain species (usually *Acioa barterii*). When yam farming is to re-commence in the fallow, the foliage is chopped off from the standing shrubs and the resulting pollards serve as stakes for yams. After a year or two, the fallow species are allowed to resume normal leaf growth. Similarly, the practice of alley cropping (Budelman, 1991; IITA, 1985) using hedge-rows of fast growing legumes (*Leucaena*, *Cassia*, *Sesbania* etc.) has been developed and recommended for yam production. At the appropriate time, the hedge-rows are defoliated and the stems serve as stakes for the yams. The widespread adoption of alley cropping for yams has not yet occurred.

Peculiar yam based cropping systems exist at various points along the flood plains of the Niger river. The farmers are able to practice a virtual monoculture of yams i.e. growing yams on the same fields every year indefinitely. This is made possible by the fact that the river, flooding these fields each year, brings in fertile alluvial sediment, in addition to having some crop protection advantages.

Although the yam crop takes only six to seven months from field emergence to maturity, the actual period of field occupancy could be longer. Farmers often plant in the dry season using materials that may not sprout and emerge for several months. After maturity, the crop is often left until complete shoot senescence and even later. Future strategies for decreasing the duration of field occupancy include using physiologically aged planting material, pre-sprouting of setts, and harvesting before complete shoot senescence. A decrease in the field occupancy duration would make for more flexible cropping systems for producing yams.

Chapter 10

DISEASES AND PESTS OF YAMS

10.1 THE YAM BEETLE

The yam beetle (*Heteroligus* spp.) is a major pest of yams in West Africa. It lays its eggs in moist ground during the early part of the dry season. This means that the eggs are usually laid in swampy areas near rivers and streams and not necessarily in the yam field. The larvae produced after hatching, feed initially on humus, and later on the roots of plants in their vicinity. The intensity of feeding decreases just before pupation, after which the adult winged beetles emerge in the early part of the rainy season (March to June). These adult beetles then migrate by flying to yam plots, being visually attracted by the foliage of the yam plants. They burrow downward at the base of the yam plants, and begin to feed on the tuber which, at this time, has begun active enlargement. Feeding continues until the end of the yam growing season in October/November. At this time the beetles mate and migrate to begin another cycle of breeding.

Yam beetles rarely kill the yam plant, but they do considerable damage to the tuber that can be harvested from it. Their feeding activity leaves hemispherical holes on the body of the tuber. These holes not only make the tuber unsightly and unmarketable, but they may also predispose the tuber to rotting during storage.

The main control measure for the yam beetle has been to dust the sets with insecticides just before planting. Unfortunately most of the insecticides previously recommended have been found to be persistent and environmentally unsuitable. Some traditional farmers try to avoid yam beetle infestation by planting very late.

10.2 YAM ANTHRACNOSE

Yam anthracnose or leaf necrosis has been reported in virtually all yam producing regions of the world. It is characterized by a blackening and die back of the leaves and shoot, giving the plant a burnt appearance. Reports (Nwankiti 1981) indicate that several fungal organisms (including *Colletotrichum* and *Glomerella*) are involved in the disease syndrome. *Dioscorea alata* appears to be more susceptible than other yam species. Wet and rainy weather is particularly conducive to the onset and spread of the disease. Infection occurs from inoculum borne within the planting sett or in the soil.

The best control measure is the use of resistant cultivars, such as TDA 291 and TDA 297. Adequate field sanitation is also useful. Control of the disease once it has developed on the crop, is very difficult and expensive.

10.3 NEMATODES

The yam nematode (*Scutellonema bradys*) and the root knot nematode (*Meloidogyne* species) are the most serious nematodes attacking yam. The yam nematode inhabits the layer just beneath the skin of the tuber. The eggs laid by the females produce larvae which are capable of infecting other subterranean tissues such as roots or tubers. The activities of the yam nematode result in extensive browning of the sub-surface layer of the yam tuber, and the resultant destruction of the meristematic zone. As such, tubers that have been infected with the yam nematode may have difficulty sprouting if used as planting material. The root knot nematode attacks growing yam tubers, producing a characteristic warty appearance on the surface of the tubers (Figure 17). The larvae occur freely in the soil, but can penetrate through the softer portions of the growing tuber and become parasitic within the tuber. The larvae soon enter into adult life, during which time only the female is parasitic. The female discharges eggs through the tuber surface into the soil. These eggs hatch to produce larvae which will again seek to infest another tuber or root material. If the tuber has been harvested and is in storage, the egg masses, as well as the larvae that they produce on hatching, remain within the tuber. The wounds created by the nematodes when they penetrate the tuber act as weak spots through which bacteria and fungal infections can occur. It is also noteworthy that since these nematodes attack and reside in the tuber, they are able to continue their activities within it during storage. The symptoms may therefore become progressively worse as the yams stay in storage.

The major control measure for the nematodes attacking yam is crop rotation, so that yam is not grown immediately after a crop that is known to cause a build up of these nematodes. Planting with uninfested material is also important. Occasionally, nematicides may be used to fumigate the soil, but this is not always economical.

10.4 YAM VIRUS COMPLEX

The yam virus complex occurs throughout the yam zone of West Africa, and is regarded as one of the yield depressing factors in yam production (Figure 18). For this reason, one major thrust of yam improvement has been the production and distribution of virus free yam material using thermotherapy and meristem culture (Ng, 1991) .

10.5 TUBER ROTS

Tuber rots, caused mostly by fungi, are particularly problematic for yams during storage, but may also occur in the field. Soft rots (Figure 19) are caused by *Penicillium* species, *Fusarium* species, and *Botrydiplodia* species, while dry rots are caused by *Rossellinia* and *Sphaerostilbe*. All the organisms which cause rots in the stored tuber are also responsible for rotting of setts after planting. In cases where the rotting organism is present in the sett, it may persist in the soil until the new tuber is formed. Infection of the new tuber will then take place. Sometimes, rotting during storage is a result of infection that occurred in the field.

Control measures for tuber rots include planting with disease-free material, as well as being careful not to wound or damage the tubers during harvesting and handling. Adequate aeration and inspection of the stored tubers should help to reduce the onset of rots and to detect rotting tubers at an early stage. Occasionally treatment of the sett or tuber with fungicide or alkaline material may help to protect it against rots.

Chapter 11

HARVESTING, STORAGE AND UTILIZATION OF YAMS

11.1 HARVESTING

In yam production, two general practices exist with respect to harvesting. In one, each plant in the field is harvested twice. This practice is therefore called *double-harvesting*. In the other, each plant on the field is harvested only once. This practice is called *single-harvesting*.

11.1.1 Single-harvesting

In single-harvesting, the crop is harvested when the season is over. Harvesting may be done at any time after large-scale leaf yellowing sets in. Since little or no more tuber material is added during the last month before vine death, the time of harvesting is not very critical. Harvesting can be done anytime from one month before senescence till 1-2 months after senescence. Tubers left unharvested for a long time after shoot senescence may begin to deteriorate.

Single-harvesting involves digging around the tuber to loosen it from the soil, lifting it, and cutting its attachment to the vine. The corm at the head of the tuber is left still attached to the tuber, but little harm is done if it should break off during handling.

11.1.2 Double-harvesting

Double-harvesting consists of a *first harvest* and a *second harvest*. The first harvest is done at mid-season, about 4-5 months after emergence. The farmer carefully digs around the tuber to free it from the soil, being careful not to dislodge or damage the roots. The tuber is then severed from the plant just below its attachment to the corm. The tuber is removed and earth is replaced over the roots. The plant then proceeds to form more tuberous tissue (re-tuberization) around the scar left after first-harvesting. When the plant has senesced at the end of the season, the second harvest is taken. This time, no particular care is taken to preserve the root system, and the tuber is freed by cutting the base of the vine rather than near the base of the corm.

The tuber obtained in the second harvest (Figure 20) differs from the first-harvest or single-harvest tubers in many respects:

(1) The second-harvest tuber appears to be fused with the corm, and the usual demarcation between corm and fleshy tuber is lacking.

(2) The second-harvest tuber is amorphous in shape in comparison to the more or less cylindrical shape of the other harvests.

(3) Much of the second-harvest tuber is lignified and fibrous, excepting the rounded projecting portions.

(4) Even at harvesting, several visible buds are present on the second-harvest tuber, and these buds are usually more widely separated from one another than the buds which may appear later in the head or corm of the other harvests.

It seems that second-harvest tubers are the main objective of double-harvesting, since they serve as ideal planting material. Indeed, in certain localities, there is a taboo against their being consumed. Their possession of widely spaced buds enables the farmer to cut the tuber into several setts, each of which can have a bud. However, it appears (Onwueme, 1977a) that these buds cannot be made to grow immediately after harvest, but must go through a period of dormancy.

In single-harvesting, the farmer is guided in his timing by the visible signal of onset of senescence. The same is true of the second harvest of double-harvesting. In these types of harvest, the farmer can postpone his harvest for several weeks after the signal without affecting yields. This is not true for the first harvest of double-harvesting. Not only is there no obvious signal to the farmer, but also the timing is more critical. If he harvests too early, he obtains many immature tubers of low market value; if he harvests too late, then there is little time left for re-tuberization, and the second harvest is jeopardized (see Figure 21).

The lack of a signal for first-harvesting highlights the need for an index of maturity for yam tubers. If such an index existed, the farmer could harvest a sample of his field, determine the maturity index, and thus be guided as to whether or not he should do his first harvest. There are two other uses that such an index could have:

(1) Because of staggered emergence, most lots of first-harvest tubers produced contain tubers at all stages of maturity. Fresh weight alone, or even dry weight, cannot fully indicate the economic value of such a lot for eating or processing. Some measure of maturity must be integrated into the assessment of the overall quality or grade of a consignment of yam tubers.

(2) In future, some farmers may not want to grow their yams to senescence. They may be interested in growing the yam till the tubers are just barely marketable. They could harvest then and grow some other crop in the same field before the dry season begins. In such a situation, a reliable maturity index for the tuber would serve as a guide to the earliest possible time at which harvesting could be done.

At present, most of the maturity indexes used for yam tubers are subjective and non-quantitative. These include the farmer's judgement, or the look of the tuber. Onwueme (1977a) developed some crude indexes of yam maturity. These were based on the percentage of the tuber length that was whitish at harvest, non-friable after cooking, or bitter after cooking. Each of these factors decreased with maturity, but a truly reliable index of yam tuber maturity has yet to emerge.

As already inferred, the timing of the first harvest is critical with respect to the yield of the second harvest. In general, the later the first harvest, the greater and more mature the first-harvest yield, and the smaller the second-harvest yield (Onwueme, 1977a). The total season's yield is less if first-harvesting is done two months before senescence (September) than if it were done a month earlier or later.

Double-harvesting is most commonly practised in the production of *D. rotundata*, and to a lesser extent in that of *D. cayenensis* and *D. alata*.

The terms 'topping', 'beheading', and 'milking' have been used in the literature to describe the first harvest of double-harvesting. These terms are considered inadequate and obsolete, and are not used here. (See Onwueme 1977a)

11.1.3 Comparison of single-harvesting and double harvesting

It had long been believed that double-harvesting would result in a greater season's yield than single-harvesting, since the first harvest presumably would stimulate even greater tuber bulking. It has been shown, however, that double-harvesting does not yield significantly more than single-harvesting (Onwueme, 1977a, nor does it prolong the life of the plants. Double and single-harvested plants senesce at approximately the same time.

Double-harvesting has the following advantages over single-harvesting.

(1) The first harvest of double-harvesting allows the season's crop to be on the market very early in the season. This is particularly beneficial because the poor storage conditions make yams very scarce once planting has occurred. The first new-season yams to break the yam famine are the first-harvest yams, produced by farmers who practise double-harvesting.

(2) The second harvest of double-harvesting results in excellent planting material of good keeping quality. During storage, the first-harvest tuber will also develop sprouts in its head-region; this further increases the potential for good quality planting material. In short, double-harvesting enables the farmer to produce the maximum of good planting material possible. He can first-harvest early and therefore produce a large second harvest; in addition, he can utilize some of the first-harvest heads if he so wishes.

On the other hand douhle-harvesting has the following disadvantages when compared with single-harvesting.

(1) Double-harvesting requires more than double the harvesting labour and effort of single-harvesting. The harvesting of yam is already a labour-intensive operation. Worse still, most of the hours spent harvesting are spent in a stooped, highly uncomfortable position. Yet double-harvesting requires the farmer to go through the procedure twice without rewarding him with a greater season's yield.

(2) Double-harvesting is much more difficult to mechanize than single-harvesting. The first harvest of double-harvesting, with its delicate avoidance of root and shoot damage, would be almost impossible to mechanize. Thus, even if, and when, most problems facing the mechanical harvesting of yam are solved, it seems probable that the first-harvesting aspect of double-harvesting will continue to be done manually. It is therefore unlikely to survive when labour becomes scarce.

(3) The eating quality of either harvest from double-harvesting is poorer than that of single-harvesting. The first harvest invariably contains numerous immature tubers; while the second harvest is mostly tough, fibrous, and unpalatable. The single-harvest tuber, on the other hand, is fleshy and palatable for nearly its entire length.

(4) As already mentioned, the timing of the first harvest of double-harvesting introduces uncertainties which the farmer may or may not be able to resolve.

In summary, it seems that the disadvantages of double-harvesting condemn it to the confines of traditional agriculture. Its high labour requirement, and the unlikelihood of its complete mechanization, tend to disqualify it as a practice for the future. The development and availability of alternative sources of planting material (pre-sprouted setts, deliberate production of "seed yams", etc.) should accelerate the extinction of double-harvesting.

11.1.4. Yields

Yields now obtainable in commercial yam production range from 8 to 30 tonnes/hectare, the exact value depending on the location, the variety planted, and the cultural practices adopted. The highest commercial yields occur in the West Indies where *D. alata* is the main species grown; the lowest yields exist among the traditional farmers in West Africa, where *D. rotundata* is the major species. In all cases, however, it seems that the yields now being realized are considerably less than the potential maximum yields possible.

11.1.5 Prospects of mechanical harvesting

Several factors concerning yam growth and production pose serious problems in attempts to mechanize its harvesting. Most yams, unlike many other tuber crops, produce only one or two tubers per stand. As such, improvements in production techniques tend to result in larger tubers rather than in a greater number of normal-size tubers. Worse still, most yam tubers are positively geotropic, growing vertically downward. As such, the larger the tuber, the deeper it penetrates and the more difficult its harvesting, whether mechanical or manual. The paradoxical situation, therefore, is that improved production techniques (fertilizers, weed control, etc.) which increase yield also increase the difficulty of harvesting. Added to this is the fact that many yam cultivars produce branching tubers which are more difficult and more delicate to lift while harvesting.

Effective mechanization of yam harvesting in future will rely on selection of cultivars with desirable tuber characteristics, as well as alteration of prevailing cultural practices and market preferences. Yam for mechanical harvesting should:

(1) have globoid tubers, which are more resistant to breakage or damage than the cylindrical or flattened tubers;
(2) have unbranched tubers with firm skin and few rootlets attached to them;
(3) bear shallow-lying tubers, which would make lifting easier;
(4) be able to grow well without staking; and
(5) be grown from small setts so that the average tuber size is not too great.

The last two requirements may complement each other. It seems that if yams are to be grown without stakes, then smaller setts planted close together may be preferable (Onwueme & Fadayomi, 1980). If growing the crop without stakes is found to give very poor yields, then an easily removable support system (e.g. the West Indian trellis system) can be substituted. The supports could then be removed just before mechanical harvesting. The use of wooden stakes, whether individual or pyramidal, seems unsuitable for mechanical harvesting.

The requirement that the setts and the harvested tubers be small may pose a problem of acceptability. In West Africa, the most important yam-growing region in the world, market preferences are for tuber size. However, if mechanical harvesting should become widespread, the relative cheapness of the smaller tubers will force the preferences to shift in their favour. In addition, processing techniques are likely to be more concerned with the total quantity of tubers than with the size of the individual tubers. The question of the market preference for large tubers will be addressed more fully in the next Chapter.

Concrete efforts at the mechanization of yam harvesting have been made in the West Indies, and to a smaller extent in West Africa. Various workers have selected several cultivars of *D. alata* which possess the requisite tuber characteristics for mechanical harvesting (Campbell and Gooding, 1962; Martin, 1974). *Dioscorea esculenta* is naturally well adapted to mechanical harvesting since the tubers are small and numerous, and can be lifted with an ordinary potato digger. J.S. Campbell (in Coursey, 1967) has described a mechanical device for yam harvesting, while Nystrom *et al.* (1973) report some success in the mechanical harvesting of *D. compsita* tubers for pharmaceutical uses.

11.2 STORAGE

11.2.1 Storage conditions

Once yams are mature and harvesting has commenced on a field, harvest progresses rapidly until the entire field has been covered. As shoot senescence marks the end of the season biologically, as well as agronomically, leaving the tubers in the soil for a longer period leads to deterioration and pest attack. Since very little of the global yam harvest each year goes into processed forms, the bulk of the yam harvest must be stored in the form of fresh tubers. Before being stored, the freshly-harvested tubers may be subjected to curing at high temperatures (29 - 32°C) and high relative humidity. Incidentally, these conditions resemble the ambient conditions in some yam-growing areas, so that in many instances, no deliberate curing is needed. Curing helps to promote cork formation and wound healing on the tuber skin (Gonzalez & Rivera, 1972). Sharply defined deep wounds reportedly heal better than deep bruises or shallow abrasions (Passam *et al.*, 1976a,b).

The yam tuber is a highly hydrated, physiologically active organ, rich in carbohydrate content. There are three main requirements for its effective storage:

a) ***Aeration.*** The storage area must be well aerated. This is necessary in order to prevent the build-up of moisture on the surface of the tuber, a situation which promotes microbial attack. Aeration is also necessary for the respiration of the tubers, and for dissipating the heat produced as a result of this respiration.

b) ***Reduced temperature.*** The temperature must be kept as low as the available technology permits, as long as it does not go below about 12°C. Most yam-growing areas have ambient temperatures between 25-35°C. At these temperatures, yam respiration rate is extremely high, thereby rapidly depleting tuber dry matter. Secondly, tuber sprouting and shoot growth, which further deplete tuber carbohydrate, are most rapid at high temperatures. Thirdly, microbial rotting of the tuber, once begun, is maximally promoted by high temperature.

Ideally, the lower the temperature, the less the storage losses from respiration, sprouting, and rotting. However, the lower temperature limit for yam storage is set by the fact that yam tubers stored below about 10°C undergo physiological deterioration and become brown. This places a severe limitation on the use of cold storage for preserving yams, and it is recommended that yams for cold storage should be kept at temperatures of 12-15°C. It is unfortunate that yams cannot be stored at close to 0°C as can many other crops, because even at 12-15°C, appreciable storage loss can still occur from respiration, sprouting, and rotting.

In the traditional setting, most farmers do not have the technology to reduce the storage temperature to even 15°C. They rely mainly on shading and indoor locations to achieve some small but significant reduction in yam storage temperature.

c) ***Inspection.*** Inspection of the stored yams must occur regularly during storage, and the storage structure or location must make allowance for this. Inspection is necessary for removing rotted tubers before they infect others, for removing sprouts which may arise from the tubers, and for monitoring any possible attack by pests and rodents.

11.2.2 Storage Structures

a) *The Yam Barn*: This is a very common method of yam storage in West Africa. The barn is essentially a framework of vertically arranged wooden poles, held together by more rigid horizontal wooden sticks, as well as by occasional stout vertical logs that have been dug into the ground. The tubers are tied to the vertical poles, with the long axis of the tuber lying horizontally. Since the barn is an outdoor structure, palm fronds or other materials are often used to provide shade, and the barn itself may be located under the shade of a big tree. The barn remains effective through the dry season, but once the next rainy season is in full swing, the barn structure and the yams stored in it tend to deteriorate. The usual recourse is to abandon the barn and move the remaining yams indoors.

b) *Platform storage*: Yams may be stored on raised platforms constructed in shady parts of the field, or sometimes indoors. This is a common mode of storage in the South Pacific, as well as sometimes supplementing barn storage in West Africa. Only one or two layers of yams are permitted on the platform so that aeration and inspection are not hindered. Leaves and shrubbery are placed on top of the tubers to provide shade.

c) *Underground Storage*. The storage of yams in ditches or clamps is occasionally practised. Cut vegetation placed over the ditch serves to moderate the temperature. However, inspection and ventilation are difficult under this method of storage, and rodent attack is usually a problem.

The losses encountered when yams are stored can occur in various ways. Tuber *rots* are particularly serious if harvesting has been done carelessly, and if the storage environment is humid or warm. Tuber *respiration* and tuber *sprouting* both consume the dry matter of the tuber, and are worsened by warm temperatures. The various treatments (such as naphthalene-acetic acid, maleic hydrazide, gibberellic acid, or gamma radiation) which reportedly prolong tuber dormancy, have been tried for the suppression of sprouting during yam storage; but hardly any of them has found widespread commercial use. *Pests* such as rodents and insects may be problematic in yam storage. A peculiar storage loss, called 'hardening' has been reported for *D. dumetorum* (Treche & Delpeuch, 1979), but may be related to tuber dehydration.

Few as they are, processed forms of yam are much easier to store than the tuber, mainly because they are less bulky, less hydrated, and less physiologically active.

11.3 UTILIZATION

11.3.1 Chemical composition

The tuber is the main economically utilized part of the yam plant. The chemical composition of the tuber varies with species and cultivar; even within the same cultivar, it may vary depending on the environmental conditions under which the tuber was produced. The approximate analysis of the various species of yam is given in Table 9. By far the largest component of the fresh tuber is water, which accounts for about two-thirds of the fresh weight. The dry matter of the tuber is therefore only one-third of its weight. However, the tail-end of each tuber has a higher moisture content than the head (Coursey and Walker, 1960), and there is a gradient of increasing percentage of moisture (and a decreasing percentage of dry matter) from head to tail. The percentage of moisture in the tuber is very high during tuber development in the field, but as the tuber approaches maturity, the moisture content begins to decrease. This decrease continues even after the tuber has been harvested, so that during storage a tuber may lose moisture to the value of 20% of its original weight.

Carbohydrates are the major dry-matter component of yams. They account for approximately one-quarter of the tuber fresh weight. Most of this carbohydrate is starch. The starch itself is mainly amylopectin and exists in the cells in the form of starch grains. The size of each individual starch grain depends on the species, but the smaller the grains, the better the quality of the starch. *Dioscorea esculenta* and *D. dumetorum* have smaller starch grains than most of the other yams. Starch grains in *D. alata* are large (up to 55 m) and ellipsoidal, with the hilum located at the narrower end. For *D. esculenta*, the grains are small (1-2 m) and angular, while in *D. bulbifera*, they are triangular and about 24 m in diameter. It seems that tubers of many yam species have the largest starch grains at the core of the tuber, and the grains become progressively smaller towards the tuber ends and towards the tuber surface.

Sugars are only present in minute quantities in yam tubers. For most species, they account for less than 1% of the fresh weight, but in *D. esculenta*, which is sweet, the percentage of sugar may be as high as 2-4% on a fresh-weight basis. It seems, too, that the sugar content of yam tubers may increase during or just before sprouting. As a result, tubers that have been stored for very long periods may develop a sweetish taste. The sugar present in yams is mostly sucrose, but small traces of glucose and fructose may also occur.

The protein content of yams is rather low, ranging from 1-2% of the fresh weight. The proteins in yam appear to be low in sulphur-containing amino-acids. Lysine and leucine are the limiting amino acids (Bradbury & Holloway, 1988). Most of the soluble amino-acids in yam are lost when the tuber is chilled. Mucilages which exude when the yam tuber surface is cut are mostly glycoproteins.

Vitamins and minerals (ash) are also minor components of the yam tuber. Significant amounts of Vitamin C are present, with values in the range 6-10 mg per 100g of tuber tissue. Traces of Vitamins A and B are also present. Calcium, iron, and phosphorus are among the components of the mineral fraction of the tuber.

Some yams may contain traces of polyphenolic compounds. These are significant since they are subject to enzymatic oxidation when the tuber is cut. They cause the cut surface of the tuber to turn brown. The main substances responsible for the browning are dopamine and a catecholamine, both of which are phenolic amines. Both catecholase and tyrosine have been implicated in the browning reaction (Tono, 1968; Adamson & Abigor, 1980), which is an undesirable characteristic in yam utilization. Terpenoids, which constitute a bitter principle in yam tubers, occur at the extreme head and tail regions, and are particularly high and dispersed in the tuber of *D. dumetorum*.

As has already been mentioned, certain *Dioscorea* species may contain quantities of alkaloids (e.g. dioscorine) and steroid derivatives (e.g. diosgenin). The former may be extracted for use as a poison, while the latter is extracted for pharmaceutical use.

11.3.2 Utilization of the fresh tuber

By far the largest proportion of yams produced annually is marketed as the fresh tuber. Only a very small fraction goes to market in processed forms.

Boiled yam is one of the simplest and commonest forms in which yam is consumed. Essentially, its preparation involves boiling pieces or slices of yam in water. It is ready to eat in about 10 minutes. However, the requisite duration of boiling depends on the species and variety. The slices may be boiled with the tuber skin still attached, or they may be peeled (removal of tuber skin) before boiling. Boiling with the skin still attached allows for the retention of a greater percentage of the Vitamin C present in the tuber (Coursey and Aidoo, 1966). In this case, the tuber skin must be washed thoroughly before boiling. The skin must also be removed after boiling, since it is not normally eaten. For species such as *D. dumetorum*, which contain bitter and toxic principles, the tuber must be detoxified before being cooked. This is done by soaking it in salt water for several hours before it is boiled, or cooked in any other way. Boiled yam is usually eaten with some kind of sauce (e.g. salted palm oil, stew, etc.), into which it is dipped before being eaten. A variant of boiled yam is yam pottage, which is produced by boiling the yam-pieces in or with the sauce.

Pounded yam is perhaps the most popular and most traditional form in which yam is eaten in West Africa. It is prepared from boiled yam. Instead of being eaten directly, the boiled yam is pounded in a large mortar until it forms a thick paste of uniform consistency. The paste is then eaten by being rolled into small balls, dipped in sauce or stew ("soup"), and swallowed without being chewed. The preferred consistency of pounded yam varies from place to place and from person to person. In general, however, most people prefer that it be a viscous semi-solid. The exact consistency that results depends on the species or cultivar of yam that was used. *Dioscorea alata* usually makes poor pounded yam. *Dioscorea rotundata* and *D. cayenensis* make better pounded yam, but even within these species there are cultivars that are more suitable than others. These differences in quality of the pounded yam probably result from differences in the characteristics of the starch grains in the various types of yam. Sometimes, the pounded yam is admixed with pounded cassava products before being eaten. This is often done in situations where yams are scarce, and the resulting product is considered inferior to unadulterated pounded yam.

Traditionally, pounded yam is produced by pounding in a large wooden mortar. The pounding process is lengthy and noisy. More recently, various mechanical contraptions have been devised to accomplish the "pounding" process. Many of these devices operate on the same principles as household blenders, and they "pound" by maceration. These machines reduce the pounding time to less than one minute, so that the food reaches the table steaming hot.

Mashed yam is prepared by mashing boiled yam. It differs from pounded yam in not being viscous and its texture is therefore loose. It is similar to mashed potato, and is eaten similarly. Mashed yam is relatively popular in the West Indies. It is not popular in West Africa, where it is occasionally fed to small children whose teeth are not formed enough to chew boiled yam.

Fried yam, roasted yam, and ***baked yam*** are other forms in which unprocessed yam can be consumed. For frying, the peeled slices of tuber are fried in hot oil (e.g. palm oil, groundnut oil). Roasted yam is produced by roasting the entire tuber in a fire, scraping off the charred outside portions, slicing the tuber, and dipping the slices in oil or sauce before eating. Baked yam is produced by baking in an oven.

Fried yam-balls are prepared from the fresh tuber by first grating the peeled tuber, mixing the grated product with spices and condiments, and frying portions of it in hot oil to form little balls. Because of the greater amount of binding mucilage that it contains, *D. alata* is usually preferred for the preparation of fried yam-balls.

11.3.3 Processed forms

The major processed forms in which yam tubers are utilized are as yam flour, yam flakes, and yam chips. The quantity of yam consumed in these processed forms is relatively small, but it is expected to continue to increase with time.

To prepare ***yam flour***, the fresh tuber is peeled and sliced into thin pieces. These pieces are then dried in the sun for several days until they are quite dry. The dried slices are then pulverized by pounding in a mortar and sieving, or by being run through a motor-driven milling machine. The resulting product is a white, powdery flour. Either the dried yam slices or the flour can be stored for several months. The storage environment must be dry to prevent the growth of mould, and must be well protected from weevils, which may infest the dried products. To prepare yam flour for consumption, it is stirred in a pot of boiling water to produce a viscous doughy mass. It is very similar to pounded yam, but it is more viscous and less white. It is eaten in the same way as pounded yam by dipping small balls of it in stew or sauce and swallowing. Yam flour production and consumption is most popular in the northern forest and semi-savanna areas of the West African yam zone. This is because it is mainly in these areas that prolonged sunshine is available for effective drying of the tuber slices.

Yam flakes are a relatively new processed form of yam and have no antecedents among traditional yam consumers. These flakes, on stirring with hot or boiling water, reconstitute into a product similar to pounded yam. They can therefore be looked upon as a form of dehydrated pounded yam. Yam flakes are produced by boiling and mashing peeled yam tubers, and roller-drying the mashed product to produce the thin flakes. The flakes are then packaged in polyethylene bags, and stored or sold. For consumption, the flakes are poured into a pot of boiling water and stirred vigorously. This produces a paste similar to pounded yam, which is eaten in the same way. The main advantage of the flakes over conventional pounded yam is that the flakes can be stored more easily than the fresh tubers used to make pounded yam. The fresh tuber, unlike flakes, is bulky to store and is prone to rotting during storage. In addition, the time required for preparation before consumption is shorter in the case of the flakes, even shorter than the time required to prepare a meal from yam flour. Also, preparation of the flakes requires no pounding. All these factors make the yam flakes potentially attractive to the urban population with their lack of time and lack of adequate facilities.

Some commercial companies, especially in West Africa, now produce and market yam flakes. There are several difficulties which these companies must overcome before their flakes become fully acceptable on the market. The consistency of the food prepared from the flakes is quite inferior to that of pounded yam, which it is supposed to simulate. Specifically, food made from flakes often lacks the viscosity of well-prepared pounded yam. The preparation of the flakes for consumption still requires considerable time spent stirring and kneading the flakes with boiling water over a fire. This is exactly the same procedure required in preparing food with yam flour. It is still not possible to prepare food from yam flakes simply by pouring the flakes into hot water in a plate, as is the case for toasted cassava flour (*gari*). The requirement that the flakes be stirred in boiling water over a fire reduces the degree of convenience attached to its preparation. It cannot, for example, be prepared exclusively with hot water from a thermos flask. The yam flakes now on the market are relatively expensive. Food made from yam flakes is much more expensive than the same amount of pounded yam prepared from fresh tubers.

All the preceding factors, of course, militate against consumer acceptance of yam flakes. However, the innovation and convenience exemplified by the production of yam flakes are indicative of what future trends will and should be. Considerable research effort is therefore being devoted in various parts of the world towards solving the major problems now facing yam flake production. The ideal flake should be able to reconstitute unstirred, in hot or warm water, into a paste indistinguishable from pounded yam. As with pounded yam, different yam cultivars result in flakes of differing quality. Efforts are now geared towards identifying the cultivars that are most suitable for flake production. Yam flakes that reconstitute into mashed yam are also being investigated, especially in the West Indies (Steele and Sammy, 1973).

Yam chips for snacks, are also a relatively new form of processed yam. They are produced in the same way as potato chips by frying thin slices of tuber in fat, and packaging them in bags. **Dehydrated yam tuber slices** are produced by freeze-drying thick slices of yam tuber. The dried slices can then be stored conveniently. When needed, they are boiled in water to produce boiled yam. The quality of the resulting boiled yam depends on the cultivar of yam used, but is generally poorer than boiled yam produced from the fresh tuber.

Certain yam cultivars can be eaten raw as a vegetable, but, for most cultivars, this practice is not recommended because of the itchiness, bitterness, or toxicity of the raw tuber. Cooked tubers taste better.

The utilization of edible yam bulbils is nearly identical with that of the tuber. Bulbils may be boiled, fried, or baked. However, bulbils as a rule require much longer cooking times than tubers. Several kinds of bulbils contain bitter or toxic principles, and therefore require prolonged boiling or soaking in water before they can be eaten.

Yam tubers make good feed for livestock, but they are not normally used for this purpose because of the availability of much cheaper alternatives. In rural settings, yam peels are often fed to domestic animals such as goats and sheep.

Chapter 12

SOCIO-ECONOMIC CHARACTERISTICS: PERSPECTIVES, PROBLEMS AND FUTURE PROSPECTS

12.1 PROBLEMS IN THE YAM DELIVERY SYSTEM

The problems facing present-day yam production are numerous. Indeed, most of the problems facing crop production handling and utilization in the developing countries seem to be present in the yam delivery system. Some of these problems have already been mentioned and will now be taken up in greater detail.

12.1.1 Excessive quantity of planting material

One of the major problems in yam production arises from the fact that small setts result in low yields per sett. Consequently, the farmer is obliged to utilize large quantities of planting material in order to realize reasonable yields per hectare. For this reason, most farmers utilize 2-5 tonnes or more of setts per hectare. This large quantity of planting material would not seem excessive if the expected yield were relatively great, but it is not. Yields of 12.5 tonnes/hectare are considered good, so that the quantity of tuber produced is only about five times the quantity of tuber planted. As a consequence, the farmer can only sell or utilize four-fifths of his harvest; one-fifth of it must be saved for use as planting material. There are very few other crops (Table 10) where the ratio of material planted to material harvested (multiplication ratio) is so low.

It is regrettable that an excessive amount of planting material is needed for yam production as this is edible. Unlike cassava and sweet potato, where the commercial planting material is not edible, yam is commercially propagated by tuber material which could alternatively serve as food. The farmer is forced to reserve a portion of his edible harvest for use as future planting material. This contrasts with cassava or sweet potato, where the entire harvest of tubers can be sold or utilized by the farmer.

There are several possible solutions to the problem of excessive planting material for yam. One solution is to utilize non-tuber material for the commercial planting of yam. Such material as yam seeds and vine cuttings readily suggest themselves. Since these materials are not edible, the quantity of material planted would be of less consequence. However, yam propagation from seeds or vine cuttings results in extremely weak plants and poor yields.

A second, and partial solution, to the problem of excessive planting material is to use very small setts. It has been found (IITA, 1974; Onwueme, 1978) that the smaller the sett size, the greater the multiplication ratio. Thus, a greater yield can be obtained from ten 100 g setts than from a single 1 kg sett, even though the total weight of planting material is the same. This approach comes close to the minisett technique currently used to generate planting material, but it does not solve the problems that result from propagation with small setts: poor emergence, and very small tubers at harvest, which may be unacceptable to the consumer.

Crop improvement and other research approaches may help solve the problem of the excessive amount of planting material required for yam production. Selection could be carried out for cultivars with a high multiplication ratio. In this regard, cultivars whose leaves expand early, and which therefore become autotrophic early, may be favoured. Research should also be directed at finding ways of increasing the leaf area per plant, starting from a given sett size. It is anticipated that increased leaf area would result in increased yield.

12.1.2 Laboriousness

Yam production is unquestionably laborious. The present-day methods of production require the performance of a very large number of tasks: clearing, planting, weeding, staking, single- or double-harvesting, barn preparation, etc. Most of these tasks are performed by hand or using hand tools, and may continue to be so for years to come. The problem seems to be that some of these tasks are specialized and tend to defy mechanization. Staking is one such task. Harvesting, particularly the first harvest of double-harvesting, is another.

The ultimate solution to intensive labour requirement in yam production lies in mechanization, and the introduction of improved cultural practices through research. Mechanized land preparation and planting are already possible. Planting on mounds, hoe weeding, and conventional barn preparation will eventually be discontinued because of the high labour costs involved.

The problems of staking, a process which now requires up to 60 man-days/hectare, will have to be tackled from many fronts. Partial solutions, such as the West Indian trellis method of staking, now exist, but even this method still requires a considerable amount of labour. The ultimate solution would be to grow yams without any stakes whatsoever, even in the cloudy forest zone. This should be commercially feasible. The yield may not be as high as for staked yams, but the reduction in yield will be less than the cost and inconvenience of using stakes. More research and crop selection effort may lead to cultivars adapted to not being staked even under reduced insolation.

For effective mechanization of harvesting, the average size of tuber harvested must be considerably reduced. This, in turn, will entail the adjustment of consumer preferences so that smaller tubers are acceptable. However, since first-harvesting is too delicate an operation to be effectively mechanized, double-harvesting, of which it is a part, will continue to be laborious and will have to be discontinued. With fully mechanized yam production, single-harvesting will be the rule.

12.1.3 Long growing season

For farmers who plant in the dry season, the interval from planting to harvesting is about 10 months. For a crop that will only yield about 3 tonnes of dry carbohydrate per hectare, this is an inordinate length of time. The reasons for this long growing season are not hard to find. For the first three months or so after planting, the tuber is dormant and sprouting may not occur. Then for a further 1-2 months after emergence, the plant is almost exclusively made up of vine, the leaves remaining small and unexpanded. Tuber initiation does not occur for yet another month. It is only in the next three months that tuber bulking occurs. The final month before harvesting witnesses no further increase in tuber fresh or dry weight (Sobulo, 1972). Thus, only about one-third of the growing season is spent channelling photosynthates into the tuber. It seems, therefore, that the length of time the yam crop spends in the field should be reduced. If this can be achieved, it should be possible to grow yam before, or following, another crop during the same season. It should also make it possible to produce a quick crop of yam in regions having a shorter rainy season where yam production is not now practicable.

One effective way to shorten the growing season of yam is to plant only tubers whose dormancy period is already over and which will therefore sprout readily. Rainy-season planting accomplishes this automatically. Where irrigation is available, the dry-season planting can also be made with 'aged' setts whose dormancy has ended. The plants would then emerge quickly and grow throughout the dry season, so that the harvest would come very early in the rainy season. Indeed, it seems that out-of-season yam production is possible starting at any time of the year. In such cases, setts from long-stored tubers, which will sprout readily, should be used. Whatever the storage age of the tubers used, the use of heads or of "seed yam" further improves the chances of early emergence, and further shortens the growing season.

Another effective way to shorten the growing season for yam is to harvest before the plants senesce. Harvesting 2-4 weeks before leaf senescence should result in no yield reduction. This practice would be particularly useful if some other crop is to be grown on the land before the favourable season ends.

It should also be possible, through crop improvement, to select yam cultivars which can give reasonable yields in a short growing season. Here again, cultivars that expand their leaves early may be preferable.

12.1.4 Low yields

The present commercial yields of yam fall far below the potential yields realizable. For example, Olayide (1972) estimated the average yield of yam per hectare in Nigeria to be only about 14% of the potential yield. This percentage was lower than that of groundnuts, cassava, cowpea, rice, millet, sorghum, or maize. The low percentage for yam results from the relatively unimproved cultural practices used in its production. There is therefore ample scope and need for the improvement of yield in yam production.

The average yields per hectare of yam have shown little or no increase for the past several years. There are several reasons for this. Many yam farmers, particularly in West Africa, have continued to practice bush-fallow agriculture. However, with increasing pressure for land, the fallow period has become progressively shorter, so that the average fertility of the farmed plots has continued to decrease. Due to decades of association with yam production, the traditional yam farmers have the feeling that they are the experts in yam production. This feeling tends to stiffen their resistance to innovative suggestions, a resistance which is innately present in farmers generally. Thus, it is probably easier to get a cowpea or tomato farmer in West Africa to change his methods than it is to make a yam farmer do so. The former learned his methods fairly recently and is not necessarily attached to them; the latter has inherited the methods from his ancestors and may consider them immutable. The introduction of other crops into former yam-growing areas has meant that, on average, yam production now occurs on poorer soils. Another effect of these introductions has been that the more vigorous and more enterprising yam farmers have generally deserted yam production, and opted to grow the newly introduced crops. The profile of the yam farmer has therefore shifted towards the older, less enterprising types. Research into ways of improving yam production has been extremely limited. As such, there has been limited opportunity for generating new ideas which would help boost yam yields.

The solution to the problem of low yields in yam lies mainly in research. Crop improvement by selection and breeding should result in the identification of cultivars with the ability to give a high yield. Cultural practices and fertilizer recommendations which will enable the high yields to be realized must be devised. Farmer-resistance to innovations will gradually fade away if the innovations result in demonstrably higher yields.

12.1.5 **Storage problems**

One of the most pressing problems in yam production is that of storage and handling. The first aspect of this problem is that of storage losses. Coursey (1965) estimated that over one million tonnes of yam tuber are lost annually during storage in West Africa alone. The total loss for the world as a whole is obviously much greater.

The second aspect of the storage problem in yam results from the fact that most of the yam produced is stored and handled in the form of fresh tuber. The consequences of this are two-fold. Firstly, the delicate nature of the tuber skin implies that handling must be very gentle and, in many cases, manual. Secondly, the high water content of the tuber makes it to be very bulky to store, handle, or convey. Every three tonnes of yam that is transported contains only one tonne of dry matter; the rest is water.

Solutions to the problem of storage losses lie in careful harvesting and handling so as to avoid bruising and infecting the tubers, and storage under conditions that will minimize losses. Further research is needed to determine precisely what are the ideal storage conditions for yam, and what chemical treatments would best counteract storage losses.

The problems associated with the bulkiness of the yam tuber can best be solved if more of the harvested tuber is processed. Processed forms are less bulky and less delicate to handle and store, and are less prone to storage losses than is the fresh tuber.

12.1.6 Consumer preference for large tubers

Yam consumers all over the world, and especially in West Africa, prefer large tubers to smaller ones. Tubers weighing less than 0.5 kg are rarely taken to market and, in general, ware tubers weigh 2 kg or more. The greater the size of the individual tubers, the greater the market price per unit weight of tuber.

The only intrinsic advantage of large tubers over smaller ones is that they possess a smaller surface area per unit weight. As such, they lose less material per unit weight when they are peeled before utilization. Larger tubers are possibly also easier to handle and store than smaller ones.

However, the consumer preference for large tubers, with the farmers' effort to satisfy this preference, is the major source of problems that continue to plague yam production. Large tubers can only result from large setts, and as has been stated earlier, the multiplication ratio for large setts is lower than for small ones. Thus there is a smaller weight of tuber produced per unit weight of sett planted. Since big setts result in plants with extensive foliage, plants grown for producing large tubers require very elaborate staking. The production of large tubers is ill-suited to mechanized methods of land preparation and tends to perpetuate the laboriousness of the production system. Large tubers growing on ridges or on the flat tend to heave and to develop amorphous tail-regions. The pressure to produce large tubers therefore tends to encourage farmers to plant on mounds, which are generally prepared manually. Large tubers tend to penetrate deeper into the soil, and therefore make the prospect of mechanical harvesting extremely difficult. Even where mechanical harvesting is not practised, the large, deep-lying tuber is more difficult to harvest, so that it is more likely to be bruised or damaged during harvesting. Such hruises are the forerunners of rotting during storage.

It seems that the only reasonable solution to the problem of consumer preference for large tubers is to try to change this preference. It is a preference that places restraining demands on the farmer, and unless the preference changes, the problems to which it gives rise will continue to hinder yam production. A change in preference has already occurred in the West Indies, and in some other parts of the world; however, in West Africa, the preference for large tubers is still strong. However, there are two factors which may accelerate the rate at which the preference changes:

i) if the production of smaller tubers can be effectively mechanized, then these tubers will become substantially cheaper than the large tubers produced by non-mechanized methods. The cost factor may force the consumer to reconsider his preferences;

ii) as more and more yam reaches the consumer in processed forms, then the size of the tuber becomes immaterial to him. In that case, consumer demand for large tubers will be replaced by processor demand for qualities that make for easier processing.

In summary, therefore, the consumer preference for large tubers is likely to decline in future. Indeed, it must if the requisite advancements in yam production are to take place.

12.1.7 **Difficulties of yam improvement**

Crop improvement through breeding and selection provides a partial solution to most of the foregoing problems of yam production. Specifically, the aims of crop improvement in yam would be to produce plants which:

(a) yield highly,
(b) are tolerant to pests and diseases, including storage rots,
(c) are semi-erect in habit and therefore can grow effectively without staking,
(d) have a short growing season,
(e) produce stout, ovoid tubers adapted to mechanical harvesting and having a tough skin resistant to bruising, and
(f) have a high protein content and a desirable flavour and texture in the cooked form.

Unfortunately, yam improvement is fraught with difficulties. The most important of these is the irregularity of flowering which makes hybridization and seed production difficult and, in some cases, impossible. For species and cultivars that flower and produce seed easily, hybridization followed by selection may serve as an effective breeding method, but for those which do not flower, or do so irregularly, other breeding methods must be used. There are promising indications that biotechnology, including genetic transformation of yam, may provide solutions to this problem. Another problem that limits yam improvement is the very slow rate at which elite clonal material can be multiplied. Conventional methods of seed and tuber multiplication result in only modest multiplication rates. However, partial solutions to the problem lie in tissue culture and in propagation by vine cuttings.

It is fortunate that many yam-growing areas of the world, particularly West Africa, feature a large number of yam species and varieties. This great variability partially offsets the difficulty of producing variability through hybridization. With such a large pool of variability already existing, selection alone can be used as a breeding tool to effect some improvements in the yam crop. This can be done in the meantime, while more sophisticated and more far-reaching crop-improvement techniques are awaited.

12.1.8 **Competition from cassava**

Competition from cassava has provided the stiffest challenge to yam production in the West African yam belt over the last few decades. Both crops are consumed essentially for carbohydrates, but cassava has several advantages over yam. It is propagated by means of the non-edible stem portion, it has a low fertility requirement and therefore does well on marginal lands, it is more tolerant of weeds and of neglect by the farmer, and it requires no staking. In addition, it is mostly commonly stored under convenient dry forms. All these factors have given cassava a clear competitive advantage over yam.

12.2 GLOBAL PRODUCTION

The world production figures for yams in 1990 are shown in Table 11. Africa accounts for nearly 96% of world production, with Nigeria alone producing nearly three quarters of the world total. Indeed most of the world and African production is concentrated in the "yam belt" stretching from Côte d'Ivoire, through Ghana, Togo, Benin, Nigeria and Cameroon. Outside Africa, yam production is important in the Caribbean and in Oceania, and its contribution to the food basket can be quite significant in certain countries in these regions. For example, Tonga derives over one-fifth of its total dietary calories from yams, while Solomon Islands and Papua New Guinea derive 8.1% and 4.6%, respectively.

World production of yams in the 1980s showed an increase (Table 2) but this increasing trend did not keep pace with population growth in the producing areas (Table 12) .

12.3 ECONOMIC CHARACTERISTICS OF THE DELIVERY SYSTEM

Estimates for the labour required for yam production vary depending on the technology employed, but they are generally in the neighbourhood of 300 person-days per hectare, with reported figures ranging from 204 person-days (Nweke *et al.*, 1991) to 940 person-days on hydromorphic soils (Dorosh, 1988). The actual figure apparently depends on the exact technology employed in the production process and the characteristics of farm location. Hydromorphic soils seem to require more labour than upland soils. Weeding usually accounts for the largest input of the labour demand, taking up one-quarter to one-half of the labour input. Planting (including land preparation) usually accounts for nearly as much as weeding, with staking and other operations accounting for the rest.

Apart from labour, another major cost item in yam production is the planting material. The farmer may sometimes save up to 20% of his edible harvest for use as planting material, or he may purchase setts ("seed yams") for planting. Either way the planting material often accounts for up to 90% of the non-labour cost of yam production. Indeed some studies (Nweke *et al.,* 1991) indicate that the total cost of yam production is shared almost equally between labour and planting material. It is clear therefore that any effort to decrease the cost of yam production must address the high labour demand and the high cost of planting material. The minisett technique for generating planting material is an attempt to reduce the cost and scarcity of planting material; but ironically the process itself is labour intensive (Asumugha and Obiechina, 1991) as well as being capital intensive. This has caused the cost of planting material to remain high despite the widespread adoption of the technique. Future labour reduction in yam production in the yam belt is not a very promising prospect. Yam farming in this area is not so much an applied science as a form of art. Weeding and planting, which consume the most labour, remain problematic because the avenues for their improvement (integrated control, mechanization, etc.) remain unavailable and costly to the average farmer.

The high labour requirement and costly planting material for yam production immediately translate to high cost of the yam produced. It is estimated that the per calorie cost of yams is nearly four times that of maize and 5.7 times that of gari (IITA, 1988; Dorosh, 1988). In the last few decades, therefore, yam producers have maintained their profitability not by reducing production cost (labour, planting material), but by maintaining high prices. Fortunately for them, yam is preferred over several other foods in the yam zone. Also it has a positive income elasticity of demand within the zone, so that as people's incomes improve, they tend to consume more yams. Thus, yam is less a food for the urban poor than is cassava. However, in the rural yam farming areas, farmers have tended to sell only what is left over from their needs, and yams have remained a major food for the rural poor.

The relatively high fertility requirement for yam production has meant that with increasing population pressure and decreasing soil fertility, there is a progressive shortage of suitable land for yam production. In many instances, yam has been replaced by cassava which is more tolerant of low fertility.

The multifarious problems that result from the consumer preference for large tubers have already been discussed. The preference for large tubers is intricately interwoven with the paucity of processed forms. However, it is uncertain whether the cultural ties that have sustained yam consumption well beyond the dictates of economics, may not begin to break down if the consumer's only contact is with the processed form, rather than with the "real" tuber. In that situation, analogues made from cassava and other cheaper sources might well suffice.

12.4 YAM FESTIVALS

It has already been mentioned that at least *D. rotundata* and *D. cayenensis* are native to, and were first brought under cultivation, in West Africa. For several decades, before the introduction of maize and cassava, yam was probably the main sustenance of the peoples of the West African yam zone. During that time, considerable importance must have been attached to the success or failure of the yam crop. It is not surprising therefore that a considerable amount of ritualism developed around the production and utilization of yams.

One of the most important manifestations of this ritualism is the *new-yam festival*, which exists in various forms in the West African yam zone. In essence, a date is fixed for the festival, and before that date, no farmer may harvest or consume the new crop of yams. On the appointed day, each farmer harvests several yams from his farm, uses part of the harvest to prepare a feast, while the remainder may be used to pay homage to his elders or friends. Considerable religious activity and social merry-making often accompany the new-yam festival. After the day of the festival, the farmer may harvest the rest of his crop at his own pace and without further restrictions.

The new-yam festival therefore marks the earliest date on which new yams may be harvested or eaten. It ensures that the new crop is ushered in formally, and that its consumption does not occur until the community as a whole gives thanks to the gods and celebrates the event. The date of celebrating the new-yam festival varies from village to village and from town to town. It should be emphasized that this formal inauguration of the new crop is unique to yam. Hardly any other crop in the yam belt has a taboo and festival connected with the date when its harvesting may commence. Crops such as cassava, maize, melon, rice, cocoyam, and okra may be harvested by the farmer whenever he feels they are mature; there is no fanfare, no celebration and no bout of thanksgiving. The fact that yams alone have a festival indicates that they occupied a singular position in traditional agriculture of earlier times, and that there is considerable sentimental attachment to them.

The most strict and most elaborate observances of the yam festivals no doubt occurred in earlier times. In more recent times, the observance of the festival has become modified for several reasons. Firstly, contact with the outside world has resulted in partial adoption of institutionalized religions (Christianity/Islam), and of some foreign cultural ideas which have altered the religious aspects of the new-yam festivals. Secondly, increasing urbanization has resulted in devaluation of traditional practices by the urban dweller, since his contact with the customs and rituals of his ethnic group is only occasional. Thirdly, other crops, especially cassava and rice, are competing very seriously with yam, so that its position of importance is seriously undermined. Despite these factors, the new-yam festival still survives, especially in the rural areas. In some cases it has reached an accommodation with the institutionalized religions, so that the festival becomes a major event on the religious calendar, but with the traditional religious rites modified appropriately. Some farmers may observe the taboo against eating or harvesting their yams before the festival, but will sustain wives and children until then on new yams purchased from neighbouring markets. Partly to cater to this kind of farmer, his village may let traders from neighbouring villages sell new yams on the outskirts of the market place, even though they will not allow new yams in the market proper before the festival date.

Ritual performances are also attendant on yam production in the field. At least once, between clearing and harvesting, the traditional farmers perform sacrifices to the god of the farm so that their yams may produce well. The sacrifice may be repeated if the crop seems to be doing poorly, or if there is a drought.

Although the present-day city dweller may not participate in yam festivals and rituals, he still retains a considerable amount of sentimental attachment to yam, and some nostalgia for it. His idea of a meal the way it was back home is a plateful of pounded yam. Even in social circles, pounded yam attracts more fervour and adulation than most other dishes. Unfortunately, yam is relatively expensive compared with many other starchy staples, so that it is the economic factor, in addition to convenience, that prevents the urban dweller from eating yams more often. However, yam still remains a heavy sentimental favourite, and the city dweller will eat it whenever he can. In the rural areas, too, yam retains its social supremacy over all other crops. The quantity of a man's yam harvest determines his status as a farmer, irrespective of how much maize, rice, etc., he produces. Also public feasting in connection with various events (including, of course, yam festivals) invariably involves preparation and serving of pounded yam. It is expected that the yam festival will undergo continuing modification with time, but will persist far into the future.

Ritualism in yam production also occurs in other parts of the world, though it does not attain major proportions outside West Africa. In New Guinea, long yam tubers are specially grown for ceremonial purposes. Such yams are believed to be inhabited by spirits, and are handled with much respect (Coursey, 1967). A kind of new-yam festival is also celebrated in New Caledonia.

12.5 FUTURE PROSPECTS: THE ROLE OF RESEARCH

For all its problems, yam has received insufficient research attention in the past. Occasional spurts of attention, especially by the international research institutes, have not been sustained. This denial of research attention has meant that many of the problems of the yam delivery system have remained unsolved. Yam is already costing too much compared with other items of equivalent dietary value, and its present consumption is heavily reliant on sentiment and tradition. Areas of research that may hold promise for reducing yam production cost include mechanization to decrease the high labour demand, biotechnology (including genetic transformation) to produce new ideotypes, processing so as to reduce storage losses, and a fresh look at the problem of scarcity and costliness of planting material. Given adequate research support, the future of yam appears quite good especially in view of its popularity and the sentiment attached to it.

SECTION C: SWEET POTATO

Chapter 13

BOTANY AND ECOLOGY OF SWEET POTATO

13.1 ORIGIN AND SPREAD

The sweet potato originated in Central America or north-western South America. Its entry into cultivation probably occurred about 3000 B.C. (O'Brien, 1972). The ancient Peruvian and Mayan civilizations of tropical America grew sweet potatoes extensively. Apart from tropical America, the tropical Pacific Islands were another area of extensive sweet potato cultivation in ancient times. The introduction of sweet potato into Europe, Africa, Asia, and even North America occurred in more recent times. Apparently, Columbus introduced it into Europe after voyages of discovery, while subsequent Spanish and Portuguese explorers and traders introduced it into Africa and Asia. Today, sweet potato is grown in nearly all parts of the tropical and subtropical world, and in the warmer areas of the temperate regions. It has remained, for centuries, an important staple for many tropical communities.

13.2 CLASSIFICATION

Sweet potato, *Ipomoea batatas* (L.) Lam., is a dicotyledonous plant belonging to the Family Convolvulaceae. This Family includes about 45 genera and 1000 species, but only *Ipomoea batatas* is of economic importance as food.

A very large number of sweet potato cultivars exists; the number is larger than for yams, cassava, or cocoyams. Many of these cultivars have developed through systematic breeding efforts, and through natural hybridization and mutations. On the basis of tuber texture after cooking, sweet potato cultivars fall generally into three groups:

(a) those with firm dry, mealy flesh after cooking e.g., Nemagold, Onokeo;

(b) those with soft, moist gelatinous flesh after cooking, e.g., Centennial, Goldrush, Kandee (this group of cultivars is erroneously referred to in the USA as 'yams'); and

(c) those with very coarse tubers which are suitable only for animal feed or for industrial uses.

Sweet potato cultivars also differ from one another in the colour of the tuber skin (usually white, brown, yellow, or reddish-purple), colour of the tuber flesh (usually white, or yellow), shape of the tuber, shape of leaves, depth of rooting, time of maturity, resistance to disease, and several other vegetative characteristics.

13.3 ECO-PHYSIOLOGY OF SWEET POTATO

Although it is grown in the tropical, subtropical, and warm-temperate regions of the world, sweet potato is essentially a warm weather crop. Growth is best at temperatures above 24°C. When temperatures fall below 10°C, growth is severely retarded. The crop is damaged by frost, and this fact restricts its cultivation in the temperate regions to areas with a minimum frost-free period of 4-6 months. Even where the frost-free period is sufficiently long, it is still essential that temperatures are relatively high during much of that period. The optimum temperature for tuber growth is about 25°C.

Sweet potato is a sun-loving crop, and does best where the light intensity is relatively high. Shading of the crop under cultivation should therefore be avoided. Day-length affects both the flowering and the tuber-formation process. Day-length of 11 hours or less promotes flowering; at day-lengths greater than 13.5 hours, flowering fails to occur. For this reason, little or no flowering occurs in temperate regions at latitudes higher than 30°N or S, since the long days of the summer months fail to induce flowering. In the tropics, sweet potato flowers frequently. Like flowering, tuber formation in sweet potato is also promoted by short-day conditions. Short days with low light intensity promote tuber formation, while long days tend to favour vine development at the expense of the root tubers.

Optimal conditions for sweet potato are found in regions with 75-100 cm of rainfall per annum, with about 50 cm falling during the growing season. The rest of the rain, falling during the non-growing season, makes it relatively easy to propagate and maintain vine growth that will be used as planting material during the next season. Although the crop can withstand drought conditions, it appears that yields are considerably reduced if the drought occurs within the first six weeks after planting (Edmond and Ammerman, 1971), or at the time of tuber initiation (Kay, 1973).

Sweet potato grows best on sandy-loam soils and does poorly on clay soils. Good drainage is essential. Soils with high bulk density or poor aeration tend to retard tuber formation and result in reduced yields (Watanabe *et al.*, 1968). A soil pH of 5.6-6.6 is preferred for sweet potato. It is sensitive to alkaline or saline soils, and such soils should be avoided.

Sweet potato is a regular crop in the highland tropics. From the highlands of East Africa, to the Andean foothills in South America, to the highlands of Papua New Guinea, sweet potato is an important aspect of indigenous highland agriculture. In Rwanda, it is the predominant tuber between 1400 and 1800 metres.

13.4 PHENOLOGY OF SWEET POTATO

Sweet potato is a perennial plant, but it is normally grown as an annual. Under cultivation, it is usually propagated from vine cuttings. The growth of such plants occurs in three more or less distinct phases:

(a) an initial phase when the fibrous roots grow extensively and there is only moderate growth of the vines;

(b) a middle phase when the vines make extensive growth, and the tubers are initiated; a tremendous increase in leaf area occurs during this phase; and

(c) a final phase when tuber bulking occurs and very little further growth of the vines and fibrous roots takes place; total leaf area stays constant early in this phase, and then begins to decline.

These phases bear a very close resemblance to the phases of growth occurring in yam.

It seems that the respective duration of these three phases in sweet potato may vary with cultivar and with environmental conditions. Scott (1950) suggests that the first phase lasts from planting to 9.5 weeks, the second phase from 9.5 weeks to 16 weeks, and the third phase for the rest of the season. However, under more tropical conditions, Wilson and Lowe (1973a) have shown that tuber initiation can begin as early as four weeks after planting, with most of it occurring four to seven weeks after planting. Very little further initiation occurs after seven weeks, so that the final tuber number is more or less determined by this time. The rest of the season is devoted to tuber enlargement.

13.5 MORPHOLOGY AND ANATOMY

13.5.1 The root system

When sweet potato is planted from stem cuttings, as in normal cultivation, adventitious roots arise from the cutting in a day or two. These roots grow rapidly and form the fibrous root system of the plant. These roots may penetrate the soil to depths of over 2 m, the exact depth attained being dependent on soil condition. This relatively deep penetration enables the crop to survive drought conditions, since it can obtain water from deeper layers of soil. As the vine grows along the surface of the soil, roots are produced at the various nodes. Such roots grow into the soil and greatly increase the effective feeding area of the plant.

Anatomically, the ordinary feeding root of sweet potato has a structure similar to that of other dicotyledonous roots. From the outside going towards the centre of the very young root, there are the epidermis, cortex, endodermis with Casparian strip, and pericycle. The very centre of the root is occupied by a four-pointed primary xylem. The primary phloem occurs between the xylem points, and there is camhium between the xylem and phloem. A few roots on each plant possess xylem with five or six points, instead of four. These roots are destined to develop into tubers.

13.5.2 The tuber

Sweet potato produces root tubers (Figure 22). They develop as a result of the secondary growth of a few roots within the top 20-25 cm of soil. Most of the tubers develop from the initial fibrous root system of the plant, but if earthing up has been carried out, some of the roots produced at the nodes will also form tubers.

It appears that roots which are destined to become tuberous are structurally different from ordinary fibrous roots at a very early stage. As has already been mentioned, they have a different number of xylem points. In addition, they possess a small pith at their centre, while ordinary fibrous roots do not, and the root primordia which give rise to them are slightly larger than those of ordinary roots. The process of secondary growth that leads to tuber formation occurs at two major locations in the root. Firstly, the normal vascular cambium lying between the xylem and the phloem produces secondary phloem on its outside, and secondary xylem plus a large quantity of storage parenchyma on the inside.

Secondly, anomalous cambium arises around individual vessels within the primary xylem. This cambium produces a large quantity of storage parenchyma both towards and away from the vessel. A small quantity of tracheids is produced towards the vessel, and a few sieve tubes are produced away from the vessel. The storage parenchyma derived from both kinds of cambium are replete with latex ducts (laticifers) Thus most of the storage tissues of the sweet potato tuber arise through the meristematic activity of the vascular cambium and the anomalous cambium. It appears that starch deposition in the cells of the cortex may also contribute to the bulk of the tuber (Indira and Kurian, 1973), although the cortex is more likely to be sloughed off, since the periderm arises from the pericycle.

One further aspect of secondary growth in tuber formation is the growth of the tuber stalk. At the same time that the storage tissues are being laid down in the tuber proper, the segment of root (stalk) attaching the tuber to the rest of the plant undergoes modification. Secondary growth occurs in it, producing an extensive amount of secondary phloem (Wilson and Lowe, 1973b). This large increase in the phloem is an adaptation which prepares the stalk for the heavy traffic of photosynthates that will occur when tuber bulking begins.

Several environmental factors affect tuber formation in sweet potato. Light exerts its influence in two major ways. Firstly, and as has already been mentioned, tuber formation in sweet potato is promoted by short day-lengths and retarded by long day-lengths. Secondly, normal growth and development of the sweet potato tuber can only occur in the absence of light. Exposure of the root system to light prevents the roots from forming tubers. Even when tubers have already developed and are growing, exposure to light results in a cessation of tuber enlargement, a decrease in the starch content, and an increase in the fibre content of the tuber (Hozyo and Kato, 1976). The retardation of tuber formation or growth by exposure to light is readily reversed by restoring the roots or tubers to darkness.

The oxygen content of the soil is another factor which influences tuber formation in sweet potato. Inadequate oxygen results in a retardation of tuber formation (Watanabe, *et al.*, 1968) and this partly accounts for the poor performance of sweet potato on waterlogged soils or soils of high bulk density.

Excessive nitrogen fertilizer in the soil delays tuber formation, while low night temperature promotes it.

Morphologically, the mature sweet potato tuber may range in shape from spherical to nearly cylindrical or spindle-shaped, in size from 0.1 kg to over 1 kg, and in length from a few centimetres to over 30 cm. The tuber is attached to the rest of the plant by a rather long, stout stalk, and tapers to a thin root at the distal end. The tuber surface is covered by a thin layer of cork, and may be smooth or irregularly ribbed. The skin, as well as the tuber flesh, contains carotenoid and anthocyanin pigments which determine their colour. Depending of the combination and intensity of these two pigments, the skin and the flesh may be white, yellowish, pinkish, or purplish, with various gradations between. Laticifers (latex ducts) which produce a white, sticky latex when cut, are present through-out the tuber flesh.

Each plant produces only a few (up to ten) tubers at the point where it was planted; but if conditions have been favourahle, supplementary tubers formed at the nodes may cause a much larger number of tubers to be produced per plant.

The tuber of sweet potato produces sprouts readily. The sprouts originate from the vascular cambium region (Schlimme, 1966). In the freshly-harvested tuber, nearly all the sprouts occur at the stalk end of the tuber, indicating a proximal dominance. As the tuber ages in storage, the intensity of the proximal dominance is reduced and sprouts can originate from the middle and distal parts of the tuber. The proximal dominance can be broken by slicing the tuber and allowing the individual slices to sprout. The proximal dominance is somewhat similar to that occurring in the yam tuber.

13.5.3 Stem and leaves

Sweet potato has long, thin stems which trail along the soil surface, putting out roots into the soil at the nodes. Stem length varies depending on cultivar, and may range from about 1 m to over 6 m. The stem is circular or slightly angular in cross-section. Stem colour is predominantly green, but purplish pigmentation is often present. Numerous lenticels occur on the stem surface. Minute hairs are present on the young stem, but these tend to disappear as the stem ages.

The internal cross-sectional primary structure of a young sweet potato stem is shown in Figure 23. The stem is covered by an epidermis which is a single layer of cells. Stomata and hairs are present on the epidermis. Internal to the epidermis is the cortex, composed of several layers of cells which contain chlorophyll. Latex ducts are also present in the cortex. Next to the cortex is the endodermis, and internal to the endodermis lies the pericycle, composed of two or three cell layers. The vascular bundles are bi-collateral, with phloem on the outside, phloem on the inside, xylem in the middle, and strips of cambium separating the outer and inner phloem from the xylem. The central portion of the stem is occupied by the pith, which is composed of large cells with intercellular spaces. The presence of pericycle and endodermis in the sweet potato stem probably contribute to the extreme ease with which the stems produce roots when placed in moist media. This is agriculturally important, since the crop is normally propagated by means of stem cuttings.

The leaves of sweet potato occur spirally on the stem in a 2/5 phyllotaxy. The petiole is 5-30 cm long, and retains the ability to grow in a curved or twisted manner so as to expose the lamina to maximal light. The petiole is swollen at its junction with the stem, and it bears two small nectaries at that junction. The lamina is extremely variable in size and shape, even for leaves on the same plant. Leaves are simple, and may be cordate or digitately lobed. The lamina is green in colour, sometimes with a purple coloration, especially along the veins. Stomata are present on both the upper and lower leaf surfaces, but are more numerous on the lower surface. The palisade mesophyll consists of one or two layers of cells, while the spongy mesophyll consists of one layer only.

13.5.4 The flower

The flowers of sweet potato are borne solitarily or on cymose inflorescences that grow vertically upward from leaf axils. Each flower has five united sepals, and five petals joined together to form a funnel-shaped corolla tube. This tube is purplish in colour and is the most conspicuous part of the flower. The stamens are five in number and are attached to the base of the corolla tube. Stamens vary in height with respect to the height of the style. In most cultivars, the two longest stamens are about the same height as the style. The filament is white and hairy; the anther is also white and contains numerous rounded pollen grains which bear minute papillae on their surfaces. The ovary consists of two carpels each of which contains one locule. Each locule contains two ovules, so that there is a maximum of four ovules in each ovary. The ovary is superior, and is surrounded by a disc-like nectary. The style is relatively short; the stigma is white and two-lobed.

Each flower, when mature, opens before dawn on a particular day, stays open for only a few hours, then closes, and wilts before noon on the same day. The length of time for which the flower is open is slightly longer if the weather is cool and cloudy. Pollination is by insects, particularly bees.

The physiology of the sweet potato flower is therefore extremely complex. Firstly, the very formation of the flowers is subject to environmental control, especially photoperiodic control. Secondly, the flower is open and receptive for an extremely short period of time, so that the chances that a given flower may fail to be pollinated are relative high. Thirdly, incompatibility complexes exist which restrict the chances that pollination will result in fertilization and seed production. Fourthly, the existence of heterostyly (variations in stamen height with respect to the style) introduces a further morphological complication into the pollination mechanism. All these features make seed production difficult.

13.5.5 Fruit and seed

The sweet potato fruit is a capsule 5-8 mm in diameter. A false septum, formed during fruit development, may divide each of the two locules into two, thereby creating four chambers in the mature fruit. Each chamber may contain a seed, but usually only one or two chambers in each fruit contain seed.

The seed is black and about 3 mm long. It is flat on one side and convex on the other. The micropyle is located in a hollow on the flattened side. Endosperm is present in the seed, in addition to two cotyledons. The testa is very hard and almost impervious to water or oxygen. For this reason, the seeds germinate with extreme difficulty. Germination can be improved by scarifying the seed either by mechanically clipping the testa, or by treating it with concentrated sulphuric acid for about 45 minutes. Freshly harvested seeds will germinate if scarified, since the only dormancy mechanism present is the impermeable testa.

Germination of scarified seeds occurs in 1-2 days. The radicle is first to elongate, and develops into the primary root system. Germination is epigeal, since the cotyledons are carried above the soil level. After emergence, the bi-lobed cotyledons expand, develop chlorophyll, and become photosynthetic. They remain functional and attached to the seedling for some time.

Chapter 14

CULTIVATION, HARVESTING AND STORAGE OF SWEET POTATO

14.1 TILLAGE AND SEED-BED PREPARATION

In the tropics, sweet potato is grown on ridges, on mounds, and on the flat. The three major methods of land preparation already described for yams and cassava are also applied to sweet potato.

The growing of sweet potato on the flat should be discouraged because the resulting yields are usually low (Kimber, 1970). Cultivation in mounds gives good yields and is extensively practised throughout the tropics, but the amount of manual labour involved in mound-making tends to make this method less commendable. In swamps or locations where the water table is high, planting on high mounds is advantageous since it reduces the risk of waterlogging in the main rooting zone of the crop.

Planting on ridges (Figure 24) is the most common method of growing sweet potato. It has also been shown that the higher the ridge, the greater the yield, up to a ridge height of about 36 cm (Edmond *et al.*, 1950). The optimal height of ridge in each case will depend on the soil type and the cultivar being grown.

14.2 PLANTING MATERIAL

Sweet potato will grow adequately if propagated by means of the tuber or by means of vine cuttings. If the crop is to be grown from tuber, then the setts should be derived from robust, healthy tubers rather than using runts and unmarketable root-pieces. The setts should be small (20-50 g) and should be planted only about 3 cm deep (Ikemoto, 1971). The use of setts derived from the tuber for direct planting of sweet potato is, however, not recommended as a general practice, because it usually results in very low yields.

The use of vine cuttings is the recommended commercial method of propagating sweet potato. It is better than using setts from tubers for several reasons. Firstly, plants derived from vine cutting are free from soil-borne disease. Secondly, by propagating with the vines, the entire tuber harvest can be saved for consumption or utilization instead of reserving some of it for planting purposes. Thirdly, vine cuttings yield more heavily than setts, and produce tubers of more uniform size and shape.

In the use of vine cuttings, pieces from the stem apex are preferred to those from the middle and basal portions of the stem (Shanmugavelu *et al.*, 1972). However, where planting material is in short supply, middle and basal vine cuttings may be used with little diminution in expected yield. The yield of tuber tends to increase with increase in the length of vine cutting used, but a length of about 30 cm is recommended. Cuttings of much greater length than this tend to be wasteful of planting material, while much shorter cuttings establish more slowly and give poorer yields.

The use of sweet potato vines as planting material creates the special problem of having enough vines available at the time of planting. Various strategies have been adopted to circumvent this problem.

(a) *Nursery plot.* This involves essentially maintaining a small plot or garden of sweet potato during the non-growing season. When planting is to be done, vine cuttings obtained from the nursery plot are used to establish the field. For most parts of the tropics, where the non-growing season corresponds to the dry season, the nursery plot is often established at stream banks, or in low-lying areas. For convenience later on when planting is to be done, the nursery plot may also be established at the edge of the proposed field. In such cases, it may be necessary to water or irrigate the nursery plot during the dry season. The nursery plot itself is commonly established at the time of harvest, utilizing vine cuttings from the previous crop. If the time interval between harvesting and the next season's planting is too long, then the nursery plot may be established later, using setts from stored tubers. The use of nursery plots is not feasible in the temperate regions where the weather is too cold for the plot itself to survive.

(b) *Production of sprouts from tubers.* This method of producing vines for planting is recommended in situations where the non-growing season is either too long or too severe for a nursery plot to be maintained. For this reason, it is the standard method of producing planting material in the sub-tropical and temperate regions. The method involves essentially causing the tubers to produce sprouts by growing them in moist beds, pulling the sprouts at intervals, and planting the sprouts in the field. The bed is made of soil or sand, the tubers are placed close together, covered lightly with soil, and kept watered. In about two weeks, the sprouts should begin to show above the soil surface, and the first batch of sprouts should be pulled 3-4 weeks after bedding. Thereafter, sprouts should be pulled at weekly intervals.

In order to maximize the production of sprouts, tubers to be bedded should be cut transversely into two or three pieces, so as to minimize proximal dominance. The tubers may also be treated with plant-growth regulators, which have been reported to improve the production of sprouts. Such treatments include dipping in ethephon at 1500 ppm (Tompkins *et al.*, 1973), dipping in 12% dimethyl sulphoxide (DMSO) for up to 20 minutes (Whatley, 1969), or treating with carbon dioxide gas at 30°C for three days before bedding (Su *et al.*, 1965). Prior heating of the tubers at 43°C for 26 hours also increases the number of sprouts (Welch and Little, 1966). It is also advantageous to disinfect the tubers with borax, boric acid or other disinfectant before they are bedded. In the temperate regions, it is essential that the sprouting beds be heated. This may be done electrically, by means of hot water, by using hot air, or by utilizing decomposing manure which generates some heat. Where controlled heating is practised, the beds are maintained at 28-30°C. At temperatures above 32°C, the sprouts tend to be long, thin, and weak.

If, as often happens, insufficient sprouts are obtained at the first pulling, it may be advisable to wait till enough sprouts are available before planting in the field. In this case the sprouts from the earlier pullings are stored with the bases dipping into moist sand or sandy loam soil in trays. When enough sprouts have been collected, they are then planted out.

(c) *Successive planting.* A strategy sometimes adopted to cope with a shortage of vines for planting is to plant only a portion of the field with the available vines. When these plants are well established, vine cuttings are taken from them and used to plant another portion of the field. This procedure is repeated until the entire field has been planted. This strategy can be combined with either the nursery plot or the tuber sprouting methods, already described. The main disadvantage of successive planting is that the plants in the field are at different ages and may mature at different times. In traditional production of sweet potato, this disadvantage is inconsequential, since harvesting, at any rate, is usually done piecemeal.

14.3 PLANTING

At planting, the vine is inserted into the soil at an angle so that 50-70% of its length is beneath the soil The placement of the vines or sprouts is done by hand in most parts of the tropics; but single-row or multiple-row transplanters which can plant sweet potato are available. Most of these transplanters have devices which water the plants or provide them with nutrient solutions as they are set in the field. It is therefore possible to plant during a dry spell, in anticipation of the rains.

The vines are normally planted 25-30 cm apart on ridges that are 60-75 cm apart. Cultivars with trailing stems are planted wider apart than those with semi-trailing stems. Sweet potato is able to compensate to some extent for variations in planting density: as plant population per hectare increases, the number of tubers per plant decreases, the mean weight per tuber decreases, and the yield per plant decreases. Where the plants are grown on mounds, two or three vine cuttings may be planted on each mound.

It is best to plant sweet potato early in the rainy season so that it has the entire rainy season to grow in. Where the rainy season is very long, planting may be delayed and timed so that the crop matures just as rainfall begins to decline. In the subtropical and warm temperate regions, sweet potato is planted in the spring, as soon as the soil has warmed up sufficiently, and the danger of frost is past.

14.4 WEED CONTROL

Weeds are a problem in sweet potato only during the first two months of growth. After this period, vigorous growth of the vines causes rapid and effective coverage of the ground surface and smothers the weeds present. For this reason, most traditional farmers do not bother to weed sweet potato plots at all. Alternatively, a single hoe-weeding is done about four weeks after planting.

The use of herbicides to control weeks in sweet potato is widely practised in various parts of the world. Diphenamid (2.7-4.4 kg/hectare) or Amiben (3.3 kg/hectare) applied on newly planted plots, or Vernolate (3.3 kg/hectare) incorporated into the soil before planting, are among the recommended herbicides in the USA (Talbert, 1967).

14.5 FERTILIZING

Sweet potato responds well to fertilizer, particularly if the land has been cropped for some time. The exact type and dosage of the fertilizer will, of course, depend on the soil type, the environment, and the cultivar grown. A 6-9-15 complete fertilizer at the rate of 560-1120 kg/hectare may be used as a general recommendation. Alternatively, nitrogen at the rate of 34-45 kg/hectare, P_2O_5 at 50-101 kg/hectare and/or K_2O at 84-169 kg/hectare may be used. When nitrogen is to be applied alone, urea or ammonium nitrate are preferable to ammonium sulphate which tends to further acidify the already acid soils in many tropical regions (Morita, 1969). Extreme care should be taken to avoid applying excessive nitrogen since this causes delayed tuberization and much vine growth at the expense of tuber growth. Indeed the K_2O:N ratio should be maintained relatively high in order to promote a high rate of tuber bulking (Tsuno and Fujise, 1968). A higher rate of potassium fertilizer is needed on non-calcareous compared to calcareous soils.

Manures may also be used for improving the fertility of sweet potato plots. This is a very common practice in small holdings and in traditional agriculture.

Fertilizer for sweet potato is best given as a split application. Usually two applications are sufficient. The first one is applied at, or immediately after, planting, while the second application is made one month later. Where mechanical transplanters are used for planting, the first fertilizer application is in the form of the starter solution that is given to the plants as they are set in the field. Where starter solutions are not used, the first fertilizer application may be:

(i) broadcast and incorporated into the soil at the time of soil preparation,
(ii) given as a spot application after planting, or
(iii) applied as a continuous or discontinuous band beside the ridges.

The second fertilizer application is either a spot application or a band application; it is never broadcast. It has been suggested that one-half of the fertilizer could be applied to the soil, while the other half could be given as a foliar dressing (Iswaran and Conty, 1974).

Sweet potato plants that are deprived of various nutrients develop deficiency symptoms. It has been reported that these deficiency symptoms develop when the nutrient level in the tissue falls below 0.12% P, 0.75% K, 0.16% Mg, 0.2% Ca, 0.08% S (Spence and Ahmad, 1967), or 18-25 ppm Mn. In phosphorus deficiency, the young immature leaves become dark-green, while the older leaves become yellowish and may develop purplish colouring on the underside. Nitrogen deficiency causes the entire plant to be stunted and light-green in colour. The leaves are initially light-green, but later become uniformly yellow. Potassium deficiency in sweet potato is characterized by yellowing of the leaves, followed later by browning and necrosis along the leaf margins. There is a characteristic spotting on the underside of the leaves. The tubers of potassium-deficient plants are of poor quality, and tend to be thin. Calcium deficiency causes the younger leaves to be light-green and the whole plant to be stunted. Magnesium-deficiency symptoms are very similar to those already described for nitrogen. Iron and manganese deficiencies cause the areas between the veins in the younger leaves to become yellowish.

Boron deficiency causes a restriction of the terminal growth of the shoot, and a production of very short internodes. The older leaves turn yellow and are shed early. The tubers are misshapen and have rough, leathery skin. Cankers which exude a brownish substance may appear on the tuber skin, and the internal tuber flesh itself may develop brownish, necrotic areas.

Mycorrhizae, growing in association with sweet potato roots have been shown to enhance phosphorus uptake (Potty, 1991).

14.6 CROPPING SYSTEMS

There are basically two kinds of production systems in existence for sweet potato: the cash crop system practised mostly in the warm temperate regions, and the subsistence system prevalent in most parts of the tropics. The former employs sole cropping and a high level of technological inputs, while the latter is characterized by intercropping and a low level of technological inputs.

Sweet potato is grown in various kinds of rotations around the world. In Sierra Leone, for example, it is often alternated with swamp rice or hungry rice (*Digitaria*). There, as in Zanzibar, the rice crop has been found to do well after sweet potato . One major usefulness of sweet potato in rotations is its ability to smother and control weeds. In the south-eastern USA, for example, nutgrass and nutsedge (*Cyperus*) weeds can be effectively controlled by growing sweet potato on the infested land. This ability of sweet potato to control weeds is due to the vigorous, almost aggressive, growth of the vine. However, this vigorous growth habit can be disadvantageous in some situations. Bits of sweet potato tubers, roots, and vines, that are left as a residue after harvesting, sprout readily during the following season, and the resulting volunteer sweet potato plants pose a serious weed problem for subsequent crops.

In many parts of the humid tropics, it is possible to grow two crops of sweet potato a year. In the drier areas, as well as in the temperate zones, only one crop per year is possible.

14.7 HARVESTING

Sweet potato is ready for harvesting in 3-8 months after planting. In most parts of the tropics the crop requires 5-6 months to mature. The exact duration of the crop varies according to cultivar and to the environmental conditions under which it is grown. Sometimes readiness of the crop for harvesting is indicated by a yellowing of the leaves. In other instances, there is no externally visible sign of readiness for harvesting. If harvesting is done too early, yields are low, but if the crop is left in the ground too long, the tubers become fibrous, unpalatable, and are prone to attack by the sweet potato weevil and various rots. Mature tubers can be recognized by the fact that the sap exuded by them when they are cut does not readily darken. Most frequently, all the tubers on a given plant do not reach maturity at the same time, so that harvesting is done at a time when a reasonable number of them are mature. This could be determined by harvesting a few representative plants and judging whether or not the entire field is ready for harvesting.

In cases where the vines have been earthed up and tubers have also been formed at the nodes, the disparity in maturity between the tubers is even greater. For this reason, many commercial producers occasionally turn back the vines in order to prevent rooting or tuber formation at the nodes.

In many traditional settings, sweet potato is harvested as needed, and there is no fixed time for harvesting. One major disadvantage of this method is that many of the tubers are past their prime at the time when they are harvested. Moreover, when harvesting is unduly delayed, the damage resulting from the sweet potato weevil tends to increase. Another form of piecemeal harvesting of sweet potato is where each plant is grown as a perennial, and individual tubers are harvested from the plant as needed. This method of harvesting is common in the highlands of Papua New Guinea. It places a heavy reliance on earthing up of the vines and the production of tubers at the nodes. Needless to say, this perennial method of cultivation is feasible only in areas where rainfall and favourable temperature are available all the year round.

In the temperate and subtropical regions, harvesting should be done before or at the onset of frost in autumn. Some farmers delay their harvest until the vines have been killed by frost. This practice results in the production of poor quality tubers that are prone to rotting during storage and is not recommended.

Most of the sweet potato grown in the tropics is harvested manually. For large-scale production, however, efficient mechanical harvesters have been devised. The first operation in mechanical harvesting is removal of the vines. This is accomplished by using vine cutters, which are essentially rotary-type or flail-type mowers. After the vines have been removed, a specially designed sweet potato harvester is used to plough out the tubers, sort them, and load them on to trucks for conveyance to the processing or storage location. Other less integrated diggers simply plough the roots out to the soil surface, from where they are later picked by hand.

Whichever method of harvesting is employed, it is important that the tubers be free of surface wounds and bruises which may impair their storage life.

The two main components of tuber yield in sweet potato are tuber weight, and tuber number. Cultivars vary in the relative contributions of these two components, but, in general, mean tuber weight increases as tuber number decreases.

14.8 CURING AND STORAGE

After harvesting, the tubers are subjected to curing in order to promote rapid healing of wounds inflicted during harvesting, and to increase the toughness of the skin (periderm) of the tuber. Curing is necessary to minimize infection by microorganisms during storage, and to make the tuber more resistant to wounding during subsequent handling. Curing should be commenced immediately after harvesting.

Curing is accomplished by subjecting the tubers to high temperature and high relative humidity immediately after harvesting. A temperature of 27-29.5°C, and a relative humidity of 85-90%, applied for 4-7 days, are commonly used. The curing is done in specially heated storage houses which must be well ventilated to prevent the accumulation of carbon dioxide. The duration of artificial curing in storage houses is dependent on the prevailing temperature at the time that the tubers are harvested. The lower the temperature, the longer the period of curing required. Indeed, it is doubtful if any artificial curing is necessary in most parts of the humid tropics, where the prevailing temperature and humidity conditions are very close to those recommended for curing. In such instances, curing occurs naturally.

After curing, the tubers are stored at a temperature of 13-16°C, and a relative humidity of 85-90%. In the tropics, where artificial curing many not be necessary, the tubers should be allowed to cure for 4-5 days under ambient conditions before they are stored away; storage at 13-16°C entails the use of refrigerated rooms. If the storage temperature is below 10°C, chilling-injury sets in, resulting in internal breakdown of the tuber tissues, susceptibility to decay, and loss of flavour. This is analogous to the chilling injury in yams, which has already been discussed.

Storage at temperatures above 16°C drastically increases the respiration rate, with consequent heat production and loss in dry matter. It causes pithiness (an increase in the intercellular spaces of the tuber), a condition that also results when artificial curing occurs for much longer than one week. In addition, sprouting, which is undesirable during storage, is promoted at higher temperatures. Several chemical treatments have been utilized to reduce sprouting in stored sweet potato. Effective treatments include pre-harvest spraying with maleic hydrazide, or treating the harvested tubers with the methyl ester of naphthalene-acetic acid (MENA) in acetone. Treating the tubers with 0.5-4.0% thiourea for 2-12 hours has also been found effective, although it increases the respiration of the tubers (Schlimme, 1966).

As during curing, the stored tubers must be well aerated. Loss of flavour results when sweet potato is stored at less than 7% oxygen or more than 10% carbon dioxide (Hassan, 1966).

Most sweet potato producers in the tropics do not store their crop under the controlled conditions recommended above. Some circumvent the need for storage by leaving the crop in the ground and harvesting only as needed. Others store the crop in underground pits covered with grass. Tubers may also be kept on platforms or stored in baskets. In general, sprouting and spoilage are common with these methods of storage, and the tubers cannot keep satisfactorily for more than one or two months.

Chapter 15

DISEASES AND PESTS OF SWEET POTATO

15.1 THE SWEET POTATO VIRUS DISEASE COMPLEX (SPVDC)

The disease is caused by a white fly-borne virus complex (feathery mottle complex) and an aphid-borne virus complex (internal cork). The SPVDC is one of the most serious diseases limiting sweet potato production in Africa. It is characterized by feathery mottle including dwarfing of plants, yellowing of veins in young leaves and yellowish spotting on older leaves. Internodes are short and the tubers produced are small. The internal cork aspects of the symptoms includes the development of corky areas within the flesh of the tubers. These areas remain distinct during cooking and are bitter to the taste. Infected tubers appear normal externally and the symptoms can only be seen when the tuber is cut.

The best control measure for SPVDC is the use of resistant varieties. Promising clones and varieties such as TIS 2498 and TIS 9265 have been produced and released by IITA. Crop rotation and field sanitation are other useful control measures.

15.2 THE SWEET POTATO WEEVIL (*CYLAS* SPP.)

This is a universally occurring insect pest of sweet potato. It has been reported to cause extensive damage to sweet potato in the USA, West Indies, West Africa, East Africa, Central America, Venezuela, Malaysia, and other countries around the world. The adult females lay their eggs in small pockets which they make at the base of the stem and in the tuber. Only one egg is laid in each pocket which is then plugged with faecal matter. The faecal matter hardens to provide protection for the eggs and the subsequent larvae. Under tropical conditions, the egg hatches in about eight days, although it may take longer if the weather is relatively cool. The larvae cause considerable damage to the tuber by feeding on it and burrowing extensively through it. Frass is also deposited within the tunnels, so that the tuber is rendered unfit for human or animal consumption. The activities of the larvae also promote the spread of infection by fungal rotters. The larva soon pupates and after fifteen to twenty days of pupation, the adult emerges. The ability of the adult to fly is very limited, so that flight is only a minor mode of distribution of the weevil. Crawling is probably more important.

Infestation by the weevils varies with season. In the tropics, they are more numerous on sweet potato grown during the dry season. In subtropical and warm temperate regions, the cold temperature late in the season markedly limits the egg laying abilities of the adult female. At temperatures between 15.5 and 21°C, egg laying is slow; below 15.5°C, egg laying stops completely. Temperature at or below freezing can kill the adult in seven days, the larva in 15 days, and the pupa in 21 days. This means that the weevils are only a problem in areas where the winters are too mild to kill off all stages of the weevil.

Tubers lying deep within the soil are less likely to be infested by the weevil. Also earthing up around the tubers results in a lower degree of infestation (IITA, 1975).

The sweet potato weevil is controlled through the following measures:

a) *Effective quarantine*. The weevil does not fly much, and is spread over great distances mostly through infected tuber material. An effective quarantine system will reduce the chances of spread by this means.

b) *Use of resistant cultivars*. The use of resistant cultivars is the surest means of control. Such cultivars include TIS 2532, TIS 3053, TIS 3017, TIS 2498, TIS 9265, as well as several others which are currently available.

c) *Prompt harvesting*. It appears that the weevils are most serious if harvesting of the tubers is delayed. Early harvesting may help to avoid infestation.

d) *Use of insecticides*. Several insecticides applied at intervals in the field have been found effective in controlling the weevil. Such insecticides include 0.1% fenthion, 0.1% fenitrothion, or 0.1% cabaryl. Soil applications of 1.0% heptachlor or chlordane have also been found effective (Hua, 1970; Subramaniam *et al.,* 1973).

e) *Crop Rotation and field sanitation*. All sweet potato residues must be eradicated when non-susceptible crops are being grown.

f) *Cultural practices* such as earthing up to prevent tuber exposure on the field, and planting with weevil-free materials.

g) *Tuber handling and treatment*. Adequate curing, and storing of tubers in underground pits can minimize infestation. Weevils can be killed by immerging infested tubers in tap water for 24 hours and drying before storage.

15.3 BLACK ROT

This fungal disease is caused by *Ceratocystis fimbriata*. The disease has been reported in the USA, the West Indies, New Zealand, Hawaii, Australia, and Africa. It can attack the plant in the fields, or it may develop on tubers during storage. In the fields it causes young plants to turn yellow and the underground stem portions to blacken. On the tuber, dark circular depressions develop and the rot may spread through the entire tuber. Infected tubers produce ipomeamarone and ipomeamaronol which are toxins and which cannot be removed by boiling or baking the tuber (Wilson *et al.,* 1970). Measures for the control of the disease are:

a) The use of resistant varieties such as B5941, B5944, and B5999, which are grown in the USA,

b) Use of disease free planting material,

c) Planting with vine cuttings instead of tuber pieces or pulled sprouts,

d) Rotation of crops. Since the fungus attacks only sweet potato, a three to four year rotation before returning to sweet potato will effectively control the disease,

e) General sanitation in the field and in the storage house. This includes washing the tuber and the handling machinery with borax or other fungicides.

15.4 SCURF, FUSARIUM WILT

Scurf is caused by *Monilochaetes infuscans*. It causes brownish blotches on the roots, tubers and other underground parts of the plants. It is controlled by planting disease-free materials, treating infected material with hot water e.g. 49°C for 10 minutes or treating infected materials with fungicides such as ferban, benomyl, or thiabendazole.

Fusarium wilt or stem rot attacks the vascular tissues and results in stunted growth of the plant. Control measures include the use of resistant cultivars (e.g. Nugget), dipping sprouts and propagating material in fungicides before planting, planting only disease-free material, and general field sanitation.

15.5 NEMATODES

Nematodes such as the sting nematode, root lesion nematode, and the root knot nematode, occasionally attack sweet potato. Control is by use of resistant varieties (e.g. nemagold), immerging planting material in hot water at 47°C for 65 minutes, or soil fumigation with nematicides.

Chapter 16

UTILIZATION, SOCIO-ECONOMIC PERSPECTIVE AND FUTURE PROSPECTS

16.1 COMPOSITION

The approximate composition of the fresh sweet potato tuber is as follows:

	%
Moisture	50-81
Starch	8-29
Protein	0.95-2.4
Ether extract	1.8-6.4
Reducing sugars	0.5-2.5
Non-starch carbohydrates	0.5-7.5
Mineral matter	0.88-1.38

The vitamins present are:

	mg/100 g fresh wt
Carotene	1-12
Thiamine	0.10
Riboflavin	0.06
Nicotinic acid	0.90
Ascorbic acid	29-40

The starch fraction is composed of about one-quarter amylose and three-quarters amylopectin. Sweet potato is unique among the tropical tubers in the sense that much of the starch is converted to maltose during cooking, and this makes the cooked product even more sugary to the taste.

The protein of sweet potato (about 5% on a dry-weight basis) consists of about two-thirds globulin. It is of high nutritive value since it contains reasonable amounts of essential amino-acids. However, the content of tryptophan and other sulphur containing amino-acids is slightly low. As with yams, cassava, and the edible aroids, the peel is higher in protein, minerals, and other non-carbohydrate constituents than the rest of the tuber. The predominant minerals in the sweet potato tuber are potassium, sodium, chloride, phosphorus, and calcium.

Most sweet potato cultivars are rich in carotene. The cultivars with yellow flesh contain a much higher amount than those with white flesh. Sweet potato is also a good source of ascorbic acid (vitamin C) and vitamins of the B complex. Unfortunately, most methods of preparing the tuber for consumption (boiling, baking, frying) result in a diminution of the content of the various vitamins. In addition, the content of ascorbic acid decreases as the tuber stays in storage.

16.2 UTILIZATION

16.2.1 Utilization of the fresh tuber

In most parts of the tropics, sweet potato is consumed without passing through processed forms. The fresh tuber is boiled, baked, roasted or fried, and consumed directly. Sometimes the fried chips are packaged and sold as a snack.

Some of the fresh tubers may be fed directly to livestock, but usually some amount of processing is required before the tubers are so utilized.

16.2.2. Processed forms for human consumption

Chips are produced by slicing the tubers into thin slices, and drying them in the sun. Such chips, when needed, can then be ground into flour. A more refined kind of flour is made by spray-drying the peeled, sliced tubers. The flour may be mixed with wheat flour for bread baking.

In order to produce canned sweet potatoes, the tubers are washed, peeled, cut and placed in cans. The filled cans are heated in an exhaust box until the slices attain an internal temperature between 82-93°C. The cans are sealed immediately and further heated at 115°C for 55-95 minutes. The canning of sweet potato is relatively common in the USA. Usually, the yellow-flesh types are preferred for canning. The tubers may be canned whole, sliced, or made into purée in water or in syrup.

Sweet potato is also marketed in the frozen form. Essentially, the washed, peeled tubers are sliced, diced, or made into purée. They are then blanched or cooked so as to prevent enzymatic or chemical discolouration, before being cooled and frozen.

16.2.3 Sweet potato as animal feed

Tubers to be used for animal feed are cleaned by washing or brushing. They are then shredded or sliced, treated with sulphur dioxide and dried rapidly, either in the sun or in heated air at 80°C or higher. The dried product can be fed whole or ground, to cattle, pigs, sheep, or poultry. Nearly one-third of the sweet potato produced in the USA is used for livestock feed.

16.2.4 Industrial uses

Sweet potato can supply starch for industrial uses, but the production costs are relatively high, and sweet potato starch competes poorly with starch from other sources. Starch extraction follows the method outlined for cassava, except that a higher pH (8.6) is required, and the risk of fermentation is greater. Sweet potato starch is used industrially in textile manufacture, and for production of alcohol and syrup.

16.2.5 Leaf consumption

The leaves and tender shoots of sweet potato are used as vegetable food in many parts of the tropics. The leaf contains, on a dry-matter basis, about 8% starch, 4% sugar, 27% real protein, and 10% ash. It also contains about 56 mg carotene per 100 g dry matter. The leaf is much richer than the tuber in protein, minerals and vitamins, and is therefore more nutritious.

The leaves are usually eaten boiled or incorporated into soups and stews. They may also be fed to livestock either fresh or in the form of silage.

16.3 SOCIO-ECONOMICS OF SWEET POTATO

16.3.1 Global production

The world production figures for sweet potato in 1990 are shown in Table 13. Over 90% of the world production comes from Asia, where China is the dominant producer. In terms of its significance in the diet, the countries that are most dependent on sweet potato for food are Solomon Islands (22.7% of total dietary calories), Rwanda (17.6%), Papua New Guinea (14.2%), Uganda (12.8%) and Burundi (12.6%) (see Table 3).

Total world production of sweet potato has shown a slight decline in the 1980s. However, there have reportedly been marked increases in specific countries (such as Rwanda) during this period.

16.3.2 Characteristics and future of the delivery system

The sweet potato possesses several characteristics that make it the ideal crop for plugging gaps in household and national food security:

1) *Drought tolerance*. While it can give good yields under well watered conditions, it is relatively drought tolerant. This means that it can be cultivated in drought years when other crops such as cereals may have failed.

2) *Tolerance of low fertility*. It does reasonably well on relatively poor soils. As population pressure and poor farming practices increase, sweet potato can replace crops such as yams and maize that have a higher fertility requirement.

3) *Low labour requirement*. Labour requirement for sweet potato production is probably less than that required by all the major tropical tubers. Once planted, it requires very little attention. In Rwanda for example, only about a quarter of sweet potato farmers do any weeding at all. The rest simply take advantage of the aggressive growth habit of the plant, and leave it to smother and take care of weeds by itself.

4) *Early maturity*. It is a short-season crop, able to produce consumable tubers in four and a half months. This means that if there has been a failure of the major preferred staple, the population does not have long to wait before the back-up crop of sweet potato is ready for consumption.

Like all the tropical tuber crops, sweet potato production is constrained by inadequate quantity and quality of *planting material*. In terms of quantity, sweet potato planting material (shoot tips and pieces) is more perishable and less storable than that of yams, cassava or cocoyams. It usually requires live nurseries of sweet potato plants to be maintained through the dry or adverse season. Such nurseries serve as sources of planting material when the growing season commences. Where facilities for such nurseries are inadequate, shortage of planting material usually results early in the season.

The quality of planting material has also been a problem, since many cultivars used by subsistence farmers are susceptible to disease, especially the sweet potato virus complex. Fortunately, recent research advances have permitted the release of cultivars such as TIS 2498 and TIS 9265, which are resistant to the sweet potato virus, relatively tolerant of the sweet potato weevil, and high yielding. More importantly, the use of tissue culture and *in vitro* techniques has permitted the rapid international dissemination of disease-free elite clones and cultivars. One problem that has often been encountered however is that the high performance of some of these cultivars sometimes may breakdown after only a few years.

Given its low labour demand and low production cost, it is surprising that sweet potato has not become more popular than it is, especially in Africa. One explanation for this is that it does not occupy the top position on the preference scale. In East Africa, demand for sweet potato is suppressed by local preference for cereals. Even in Rwanda, maize and beans are preferred. In the West African yam zone, the sweetness of the sweet potato is considered an objectionable factor. Apparently, the populace would want a sweet potato that simulates yam, and which is therefore not sweet.

Sweet potato is the most "temperate" of the tropical tuber crops. It is grown to an appreciable extent in several temperate countries, including some developed countries (USA, Japan) with advanced agricultural systems. The production systems for sweet potato as a cash crop in these countries differs considerably from the near-subsistence production of sweet potato in many developing countries. These cash crop systems employ all the modern technological inputs. Surprisingly, few of these technologies have filtered down to the subsistence production systems. Nevertheless, it is a promising sign for the future of the sweet potato that this reservoir of production technology in developed countries may eventually be tapped to improve the sweet potato delivery systems in the tropics.

A newly emerging potential for sweet potato is that it is one of the eight crops chosen by the United States National Aeronautic and Space Administration as a possible food source for long term manned space missions (Hill *et al.*, 1988). It was chosen mainly on the basis of its palatability, versatility and nutritional contents of the roots and shoots. How far this potential will be realized remains to be seen.

SECTION D: EDIBLE AROIDS

Chapter 17

BOTANY AND ECOLOGY OF EDIBLE AROIDS

17.1 KINDS OF EDIBLE AROIDS

The monocotyledonous Family Araceae (the aroids) contains several plants which are cultivated and used for food in various parts of the tropics, as follows:

(a) *Colocasia esculenta* (L.) Schott (taro, old cocoyam, eddoe, dasheen).

(b) *Xanthosoma* spp. (tannia, new cocoyam) of which *X. sagittifolium* is the most important, while *X. atrovirens, X. violaceum,* and *X. caracu* are of lesser importance.

(c) *Alocasia* spp. (giant taro), which includes *A. macrorrhiza*, as the main cultivated species, with *A. indica, A. fornicata,* and *A. cucullata* as minor species.

(d) *Cyrtosperma chamissonis* (swamp taro).

(e) *Amorphophallus campanulatus* (elephant yam). *A. oncophyllus, A. varialbis,* and *A. rivieri* are also edible.

Alocasia, Cyrtosperma and *Amorphophallus* are cultivated globally to a very limited extent. They are important food crops only in certain communities in India, south-east Asia, and the Pacific Islands. By far more important, and more extensive in their cultivation, are *Colocasia* and *Xanthosoma,* which are the main crops dealt with here. *Colocasia* and *Xanthosoma* are together called cocoyams in many parts of the world, especially in Africa. For convenience, this terminology will be used here when both crops are referred to collectively. When distinction is intended, the term 'taro' will be used for *Colocasia*, and 'tannia' for *Xanthosoma*. It should be noted, however, that each of these common names is only one of several common names that exist for these crops.

17.2 CLASSIFICATION AND BOTANY OF TARO

Taro originated in south central Asia, probably in India or Malaysia, Apparently, cultivation of taro as a crop also originated in this region. During prehistoric times, its cultivation spread to the Pacific Islands. Later it was taken to the Mediterranean area and to West Africa. From West Africa, the crop spread to the West Indies, and to the tropical parts of America. Today taro is grown in nearly all parts of the tropics, as well as in some subtropical regions.

Taro, as already stated, belongs to the genus *Colocasia* within the monocotyledonous family, Araceae. Further classification of taro into species and finer groupings is complicated by the fact that, like many other vegetatively propagated plants, there is an almost continuous gradation of characteristics. However, it is generally agreed that *Colocasia esculenta* is the major cultivated form of taro. Numerous botanical varieties of the plant exist. Numerous agricultural cultivars of taro also exist, such as Samoa Hybrid and Alafua Sunrise which are grown in the Pacific region (Wilson *et al.*, 1991).

It appears that the chromosomes of taro are prone to unpredictable behaviour during cell divisions. As a result, the chromosome number per cell is not uniform within the crop. Chromosome numbers $2n$ = 22, 26, 28, 29, 38, and 42 have all been reported for taro from various locations. It is probable, therefore, that new types of taro originate quite frequently in nature or under cultivation.

Taro is a herbaceous plant consisting of a central corm from which cormels, roots, and the shoot arise (Figures 25 & 26). The shoot consists mainly of the leaves which develop in a whorl from the apex of the corm. The terminal bud remains very close to this apex. The leaves are therefore the most prominent aerial organ of the plant. Plant height, which is determined by the height of the leaves, ranges from 1 to 2 m. Each leaf consists of a long erect petiole and a large lamina. The attachment of the petiole to the lamina is not at the edge of the lamina, but at some point in the middle of the lamina. This form of attachment (peltate leaf) is a diagnostic feature which generally distinguishes taro from tannia and the other edible aroids. A major exception to this rule are the 'piko' group of taro in Hawaii which, like tannia, have hastate leaves. Leaf lamina in taro is large, thick, entire, and glabrous. It is more or less rounded, except for a slight indentation at the base, and pointedness at the tip. Three main veins radiate from the point of attachment of the petiole, and several prominent lateral veins originate from the main veins. The petiole may be more than 1 m long; it is thick along its entire length, but is thicker at the base than near the attachment to the lamina. The base of the petiole, where it is attached to the corm, is flared out so that it clasps around the apex of the corm. The petiole is solid throughout its length, but it is replete with large air spaces. These air spaces presumably function as conduits for aeration of the subterranean organs when the plant is grown under swamp or flooded conditions.

Flowering in taro is only occasional, and many cultivars have never been known to flower. Flowering can be induced artificially by applying gibberellic acid (Wilson, 1979). When flowers occur naturally, they appear shortly after planting, sometimes before any of the leaves have expanded. The inflorescence (Figure 27) arises from the leaf axils, or from the centre of the cluster of unexpanded leaves. A plant may bear two or more inflorescences. The peduncle is stout and relatively short. In addition to the peduncle, there are two major components of the inflorescence: the spadix and the spathe. The spadix is essentially the spike inflorescence consisting of a central axis on which numerous, small, sessile (without pedicel) flowers are attached. The spathe is a large yellowish bract which sheathes the spadix from the base and partly surrounds it. The spathe is about 20 cm long and is rolled inward at its tip.

The spadix is 6-14 cm long. The female flowers occur at the base of it, while the male flowers occur near the tip. In the region between the male and female flowers are a group of sterile flowers; the extreme tip of the spadix has no flowers at all. This sterile appendage of the spadix is much longer in the eddoe types of taro than in the dasheen types. In eddoe, the appendage is longer than the male section of the spadix, while in dasheen, it is shorter. Each female flower consists essentially of a small ovary bearing a sessile stigma. The ovary has one locule, which contains numerous ovules. Each male flower consists of 2-6 sessile anthers which are fused together. Pollen grains are spherical. The flowers are fragrant, and pollination is probably by insects, especially flies.

Fruit and seed setting in taro are even rarer than flowering. Many inflorescences wither without setting any seed. When fruiting occurs, the fruits are clustered at the basal portion of the spadix. Each fruit is a berry about 3-5 mm in diameter. The seed is hard, contains endosperm, and germinates with extreme difficulty.

The root system of taro is fibrous and is confined mostly to the top layers of the soil. The roots arise from the lower portions of the corm.

The corm of taro is a cylindrical or spherical structure which represents the main stem of the plant. In the dasheen types it may be up to 30 cm long and 15 cm in diameter, but in the eddoe types, it is usually smaller. Petioles of existing leaves arise from the apex of the corm, while the positions of previous leaves are marked by prominent rings of leaf scars. Lateral buds exist just above each leaf scar and in the axils of existing leaves. The outer periderm of the corm is brownish and relatively thick. Within it lies the ground parenchyma, which is densely packed with stored starch. Scattered vascular bundles and a few laticifers occur in the ground parenchyma. Cells containing raphides (bundles of calcium oxalate crystals) occur in the tissues of the corm, and, to a lesser extent, in all other parts of the plant. They account for the itchiness of the uncooked corm. As the corm ages, it becomes progressively denser and more woody.

The cormels arise from the axillary buds present on the corm. Morphologically, they represent the lateral branches of the plant stem, while the corm represents the main stem. Each cormel is a fleshy, tapering structure, being relatively thin at its point of attachment to the corm, and fatter and rounded towards the distal end. A terminal bud is present at the distal end of the cormel. Scale leaves are present on the body of the cormel. An axillary bud is present in the axil of each scale leaf. It appears that each cormel is, indeed, a stem tuber, as evidenced by its possession of a terminal bud, scale leaves, and axillary buds. Eddoe types of taro tend to have more numerous cormels than dasheen types. Cormels, like the corm, are edible and are usually less woody than the corm.

Secondary corms may also arise from the axillary buds of the corm of the taro. Such secondary corms usually give rise to suckers or daughter plants around the main plant.

17.3 CLASSIFICATION AND BOTANY OF TANNIA

Tannia originated in tropical America where it was first brought under cultivation. From there, it has spread to south-east Asia, the Pacific Islands, and Africa. Spread of the crop to the South Pacific and Africa occurred in recent times, probably in the 19th century. It arrived in these places later than taro.

Tannia belongs to the genus *Xanthosoma*, which is also a member of the Family Araceae. Like *Colocasia*, the taxonomy of *Xanthosoma* at the species level is extremely confused. However, there is general agreement that the most widely cultivated species is *X. sagittifolium*, which itself exists in numerous forms. Other edible species are *X.*

atrovirens, which has yellow flesh, *X. caracu*, which has white flesh, and *X. violaceum*, which has pinkish flesh. The former two species are popular in the West Indies, while the latter one is grown in the Philippines. The reported chromosome number for tannia is $2n = 26$.

Tannia has a close resemblance to taro in its general botanical characteristics. However major differences exist. Tannia is a more robust and taller plant than taro. Like taro the plant consists of shoot, root, corm, and cormels.

The leaf lamina of tannia is more or less heart-shaped; there is a deep indentation which divides the base of the lamina into two lobes. The petiole is attached to the lamina at the indentation. The leaf is therefore hastate, in contrast to the peltate leaves of most taro types. A thick mid-rib runs from the point of attachment of the petiole to the tip of the leaf, while two other prominent veins run to the basal lobes of the leaf. Each of these main veins gives off branches, which, in turn, branch repeatedly to give a reticulate network of veins. In addition, there is a prominent vein which runs along the margin of the leaf of tannia. This marginal vein is absent in taro as well as the other edible aroids, and it serves as a distinguishing feature for tannia. As with taro, the petiole of tannia has numerous air spaces and is flattened at its attachment to the corm.

The inflorescence of tannia (Figure 27) is also a spadix, subtended by a spathe. The spathe is pale-green in colour. The spadix is cylindrical and about 15 cm long. The female flowers occur at the base of the spadix, the male flowers towards the tip, and sterile flowers between the two regions. The length of the male region of the spadix is 3-4 times the length of the female region. Unlike taro, there is no sterile appendage at the tip of the spadix. Each female flower of tannia consists of an ovary on which lies a yellow disc-like stigma. The ovary contains many locules, and the ovules are arranged in axile placentation. Each male flower comprises six stamens whose anthers are united. The fruit is a berry, although fruit and seed production in tannia are extremely rare.

The root system of tannia is, like that of taro, fibrous and superficial, being confined mostly to the top metre of soil. The corm is more or less spherical; the cormels are flask-shaped, and usually larger than those of taro. Ten or more cormels may be produced on the corm.

17.4 ECOLOGY AND PHENOLOGY OF COCOYAMS

An important characteristic of cocoyams is their high moisture requirement. Both taro and tannia require rainfall above 2000 mm per annum for the best yields to be obtained. When rainfall is low, corm growth is reduced. Among the taros, the eddoe types can tolerate drier conditions better than the dasheen types. Indeed most of the dasheen taros do best under flooded conditions.

Cocoyams are warm-weather crops and require average daily temperatures above 21°C. Tannia reportedly needs a minimum temperature of 13°C, optimum of 27°C and maximum of 32°C for normal growth (Hackett, 1984). Cocoyams cannot grow well under frost conditions.

Dasheen types of taro grow best where the soil is heavy and has a high moisture-holding capacity. Eddoe types of taro prefer well-drained loamy soils that have a high water table. For either type of taro, flooding and waterlogging of the soil are well tolerated, and are indeed preferred by certain cultivars. Apparently, taro plants growing under flooded or reducing soil conditions are able to transport oxygen from the aerial parts of the plant to the roots; this enables the roots to respire and grow normally. However, flooded systems for taro production may require periodic aeration in order to avoid iron and manganese toxicity. Unlike taro, tannia cannot tolerate waterlogging; it therefore grows best on deep, well-drained soils. The water table should be at least 45 cm below the soil surface. For all cocoyams, a soil pH of 5.5-6.5 is preferred. Mycorrhizae associated with cocoyam roots apparently facilitate nutrient absorption. Cocoyams can tolerate saline soils better than many other crops.

While cocoyams grow best under the full intensity of sunlight, they appear to tolerate shade more than most other crops. Also, corm and cormel formation and growth are promoted by short-day conditions, while flowering is promoted by long days.

Cocoyams are essentially lowland crops. Although they have been grown at altitudes as high as 2000 m, the yields at such high altitudes tend to be very poor. The relatively cool temperatures encountered at high altitudes probably contribute to keep the yields low. In Papua New Guinea, the maximum elevation for tannia is about 2200 m.

Cocoyams are perennial herbs. The period immediately after planting or onset of the growing season is marked by a rapid increase in shoot growth. This increase in shoot growth continues until about six months after planting; thereafter the growth of the shoot (mostly leaves) as well as the total dry weight of the shoot declines. This general pattern of growth relates both to taro (Ching, 1970), and to tannia (Spence, 1970). In the case of taro, the decrease in shoot growth after six months is observed as a reduction in leaf number and leaf area. There is also a shortening of the leaf petiole which is reflected in the field as a decrease in the height of the plants. Throughout the life of the cocoyam, there is a continual turnover of leaves, with the older ones dying as new ones appear.

The growth pattern for the corm and cormel of cocoyam is, to some extent, the inverse of that of the shoot. Corm formation begins when the plant is about three months old. Corm and cormel growth is slow during the first few months after planting but increases during the latter part of the season when shoot growth is decreasing. This relationship is roughly similar to that which is observed between shoot growth and tuber growth in yams.

Flowering in cocoyam is relatively rare. When it occurs, the flowers appear during the early part of the season. At the end of the growing season, the cocoyam shoot may wither completely, leaving only the corm and cormels to perennate. When the favourable season returns, some buds on the corm and cormels will give rise to suckers which will grow into new plants around the original parent plant. If the adverse (non-growing) season is not too severe or too protracted, the shoot may remain alive until the onset of the next growing season.

Chapter 18

CULTIVATION OF COCOYAMS

18.1 LAND PREPARATION FOR COCOYAMS

Taro is grown under flooded (lowland) or unflooded (upland) conditions. Yields are generally higher under flooded conditions, but the time required for the crop to mature is longer, and the amount of effort expended in land preparation is greater. Tannia is grown almost exclusively under upland conditions.

For flooded culture of taro, land preparation involves essentially clearing, ploughing, disking, harrowing, and puddling. In Hawaii, where land preparation for taro culture has attained a high degree of mechanization, ploughing and disking are done with rubber-tired farm tractors equipped with special track devices (Plucknett *et al*., 1970). Puddling is then done with a disk or spike-tooth harrow. Puddling does not necessarily result in higher yields (Ezumah, 1973), and may sometimes be omitted. In most of the fields, land preparation is done while the field is wet. In other localities, other kinds of equipment or even hand tools are employed in land preparation for flooded taro culture. Whatever means of preparation has been employed, the goal is to have a field that is relatively level and has dikes or embankments on all sides so that water can be impounded within the field. The soil should be sufficiently puddled so that percolation of impounded water is reduced to a minimum.

For upland culture of taro or tannia, land preparation also involves clearing, ploughing, and harrowing. There is no necessity to build dikes around the field since no standing water will be needed. There is also no need to ensure that the field is level; but if furrow irrigation is to be utilized, the field must be gently sloped and furrows must be constructed. Planting is most commonly done on the flat, although planting on ridges or in beds may sometimes be practised. It has been shown that planting on ridges does not necessarily give higher yields, although it may be of some advantage if mechanized harvesting is to be done.

In traditional, less mechanized, cocoyam production, planting is done on low mounds, or in holes dug in unploughed land. In many parts of West Africa, for example, cocoyams are commonly grown on low mounds which are identical to the mounds prepared for the production of yams or cassava.

18.2 PLANTING MATERIAL

The commercial planting material used for cocoyam production may be:

(a) small corms, or setts cut from larger corms;

(b) cormels, or setts cut from large cormels; or

(c) stem cuttings consisting of the apical portion of the corm and the lower 15-25 cm of the petioles; this type of stem cutting is referred to as 'huli' in taro culture in Hawaii.

Setts from corms normally give a higher yield than those from cormels, while the stem cuttings give a higher yield than even setts from corms. The high yield of cocoyam from the stem cuttings may be due to the fact that they produce a greater number of roots and a greater total leaf weight than the other two kinds of planting material (Moursi, 1954). The optimal weight of sett used for cocoyam planting from corm or cormel pieces is about 150 g.

Three methods are currently available for the rapid multiplication of cocoyam planting or clonal material. The first method involves essentially the removal of the apical dominance exerted by the apical bud of the corm, thereby enabling the lateral buds of the corm to grow. In practice, the apical dominance is removed by destroying the apical bud, slicing the corm into horizontal slabs, or excising the lateral buds and growing them separately. Where the apical bud is destroyed or the corm is sliced, the lateral buds must later be excised after they have begun to grow. After excision, they are planted individually and allowed to continue growth. Secondly, the minisett technique originally developed for yam has been applied for rapid generation of cocoyam planting material. In this case, setts in the range of 30 g, appropriately protected with seed dressing chemicals, are used for planting. The third method of multiplying cocoyams rapidly involves mericloning (Mapes, 1973). Meristems from the apical or lateral buds of the corm are grown in special tissue culture. The meristem then proliferates to produce a mass of cells which can differentiate into small cocoyam plants. This method is important for generating disease-free clonal material for international distribution, and for germplasm conservation.

18.3 TIME OF PLANTING

In the tropics the major determinant of the time of planting for cocoyams is the availability of moisture. Where there are distinct rainy and dry seasons, planting is done shortly after the rains have become regular. Where irrigation facilities are available, planting can be done at any time of the year. This is the practice in Hawaii. In this case, the time of planting for a particular farmer is, to some extent, determined by the time when his previous crop matures. This is because the previous crop provides planting material for the new crop. When cocoyams are grown in more temperate countries (e.g., Egypt), planting is done in the spring, so that the crop can grow during the warm summer months.

18.4 SPACING

The general relationship between field spacing and cocoyam performance is as follows: close spacing increases the corm yield per hectare and the shoot yield per hectare; but it decreases the corm yield per plant, the contribution of sucker corms to the yield, and the leaf area per plant. This has been found true from trials in Brazil (Silva *et al*., 1971), in India (Purewal and Dargan, 1957), and in Hawaii (Ezumah, 1973; Ezumah and Plucknett, 1973). High yields per hectare continue to be realized even if spacing is decreased to 30 cm x 30 cm; but at such high planting densities (109,000 plants/hectare), the amount of planting material is enormous, and the net return per unit of planting material is low. As a compromise, a spacing of 60 cm x 60 cm is recommended. This is the spacing recommended for Fiji (Sivan, 1973), where the wide spacing of 90 cm x 90 cm previously used by the farmers resulted in low yields. Similarly, cocoyam grown in West Africa at spacings of 1 m x 1 m, or even wider, should be spaced closer in order to improve yields. Indeed, most cocoyam growers around the world employ spacings that are too wide, and increases in yields should result from closer spacing. Weed incidence in the field should also decrease when closer spacings are employed. For flooded taro culture in which moisture is not limiting, optimal spacing is closer than for upland culture.

Since tannia is a larger and more vigorous plant than taro, the optimal spacing should be slightly wider than that for taro.

In many traditional settings, cocoyam is grown as an inter-crop. Spacing under such conditions is not fixed, but is determined by the density of the other crops that share the field.

18.5 METHOD OF PLANTING

For upland cultivation of taro or tannia, the setts are planted 5-7 cm deep in the soil. Where stem cuttings are used, the top of the corm-portion of the cutting should lie 5-7 cm beneath the soil. It is important that the sett piece or the stem cutting should not be planted too shallow. Shallow planting causes the new corm to develop above the soil surface, or to be partially exposed. Such exposed corms are prone to damage by pests before they are harvested. Also, shallow planting results in extremely shallow rooting, so that the plant is prone to moisture stress. Furrows about 60 cm apart may be made in the field; the setts are then dropped in at intervals, and covered up.

Application of mulch soon after planting is sometimes beneficial in upland cocoyam culture. The mulch usually consists of dead leaves and grasses; this serves to conserve moisture and reduce the temperature around the sett. In taro culture in Japan, the use of polyethylene mulch has been tried. The strip of polyethylene, up to 1 m wide, is spread over the planted crop row; this serves to conserve moisture, and control weeds. More importantly, under temperate conditions, it serves to raise the temperature of the soil early in the growing season, when low soil temperatures are likely to be limiting growth. Black polyethylene has been found to give better weed control and higher yields than transparent polyethylene. One major limitation of the polyethylene mulch is that suckers coming up later around the main plant tend to be entrapped under the sheet of polyethylene.

In flooded taro culture, planting is done into 2-5 cm of standing water. The sett or sett cutting is inserted by hand into the loose puddled soil. Strings placed across the field serve as guides in aligning the plantings. The traditional method of planting flooded taro is an extremely unpleasant task, involving hours of stooping, and standing in mud. Vast efforts are therefore being made to mechanize the procedure. The use of a tomato transplanter to plant the crop into fairly dry soil has proved reasonably successful (Plucknett *et al.*, 1973). In this case, flooding of the field would occur immediately after planting.

18.6 WATER MANAGEMENT IN COCOYAM CULTIVATION

Taro and tannia are crops that require ample moisture throughout their growing season. Their large leaves are extensive transpiring surfaces through which large quantities of water are transpired each day. In addition, intermittent moisture stress results in production of corms that have a dumb-bell shape and are poor in quality. Ample supply of water to the crop at all times is a goal that the farmer must strive to attain, and the management of water is one of the factors constantly calling for his attention.

Nowhere is water management more critical or more arduous than in the flooded culture of taro. The preparation of land for flooded taro is itself dictated by the need to impound water in the field. Building of dikes, levelling of the ground, puddling of the soil, building of canals, and diversion of streams are all steps taken to get water into the field and keep it there. The crop is planted into standing water 2-5 cm deep. When the roots have developed sufficiently, the water level is raised so that the base of the plant is kept submerged. As the base of the plant grows above the existing water level, the level is raised again, and so on until harvesting. Occasionally, the field may be drained for fertilizer application, but should be re-flooded a few days after the application. It is necessary that the water on the flooded field be replenished, from time to time, with fresh water. If this is not done, the warm stagnant water may cause a severe incidence of root rot to develop.

Even in the upland culture of taro and tannia, it is still important to ensure a constant availability of water. Where rainfall is irregular, irrigation facilities must be provided. Either furrow irrigation or sprinkler irrigation may be practised.

Flooding of taro results in significantly higher yields than when it is grown with furrow or sprinkler irrigation (Ezumah, 1973; Ezumah and Plucknett, 1973). The greater yields associated with flooding have been attributed to a greater ability to produce suckers, and to the greater leaf area that results. The rate of leaf senescence is also lower. Flooding may also provide an effective method for controlling weeds. However, the much more elaborate land preparation and water management required for flooded taro culture tend to detract from the greater yields realized. In comparison with upland irrigation methods, furrow irrigation has been found to result in greater leaf area and greater total yields than sprinkler irrigation. The yield of sucker corms is greater under furrow than under sprinkler irrigation.

18.7 WEED CONTROL

Cocoyam plots are particularly prone to weeds during the first three or four months when the leaf canopy is sparse. When canopy closure occurs, weeds are kept reasonably in check. However, this situation is only temporary. The life cycle of cocoyams is such that, later in the season, new leaves become progressively smaller, so that even if canopy closure was achieved in mid-season, the canopy is again open, and weeds can again thrive. Therefore, the weed control problem in cocoyam is most critical at two distinct stages: during early vegetative growth, and during the period of starch accumulation and maturation.

For upland taro, weeding is commonly done with hand tools. Such mechanical weeding should be as shallow as possible in order to avoid extensive damage to the taro roots, which are very superficial. Various herbicides have also been recommended. Prometryne at 1.2 kg/hectare, applied before emergence, gives 4-8 weeks of control, and has been recommended in the West Indies and Samoa. Dalapon at 3 kg/hectare, applied after planting but before emergence, has also been found effective. TCA at 5.6 kg/hectare, used in conjunction with Diuron (3.4 kg/hectare) or with Atrazine (3.4 kg/hectare) can control weeds in upland taro. Trifluralin and Ametryne have been used successfully. Where polyethylene mulching is practised, the mulch is able to control weeds.

For flooded taro, the flood itself provides some degree of weed control. Herbicides can also be added to the irrigation water. Nitrofen at 3-6 kg/hectare, or RP-17623 at 1.5 kg/hectare have given good weed control in flooded taro in Hawaii (Pena *et al.*, 1971). Prometon, Prometryne, Ametryne, or directed oil sprays may be used after the land has been drained.

For tannia, normally grown under upland conditions, weeding with hand tools is also commonplace. As with taro, deep penetration of the soil by the weeding tool should be avoided. Herbicides which have been used for weed control in tannia include pre-emergence application of Diuron at 1-2 kg/hectare, which is recommended for St. Vincent and the Grenadines. TCA at 5 kg/hectare may be added to the Diuron for greater effect. Atrazine may be used on heavy soils, while Linuron and Simazine may be used on light soils.

18.8 FERTILIZING TARO

Reports from various regions indicate that taro responds well to fertilizer applications. In general, the plant has a high requirement for potassium and calcium. Also, flooded taro usually requires greater quantities of fertilizer for maximal yields than does upland taro. This is probably a reflection of the longer duration of the flooded taro on the field, and the greater yields derived from it. Pena (1967) has reported that, in Hawaii, the highest yields were obtained with 560 kg/hectare of nitrogen fertilizer in upland culture; the yield was less for higher and lower amounts of nitrogen. For flooded taro, yields continued to increase up to 1120 kg of nitrogen per hectare. Phosphorus fertilizer, with 560 kg/hectare in upland taro and 1120 kg/hectare in flooded taro, gave the highest yields. Potassium fertilizer up to 1120 kg/hectare increased yields in upland taro; but yield of flooded taro was not increased by potassium fertilization. In India (Purewal and Dargan, 1957), fertilizer at the rate of 112 kg N + 56 kg P_2O_5 + 56 kg K_2O per hectare has been recommended as giving the highest yields in taro. Nitrogen fertilizer, applied at 200 kg of ammonium sulphate per hectare, has also been recommended. On an acid, clay soil in Puerto Rico, Samuels and Velez (1968) obtained no response to phosphorus, potassium, magnesium, or calcium fertilizer, but nitrogen at 56 kg/hectare increased yields. Excess nitrogen (112 kg/hectare) depressed yields, just as it did with the above experiments in Hawaii. A general application of 40-80 kg/hectare for N, 13-26 kg/hectare for P, and 48-96 kg/hectare for K has also been recommended for taro (Jacoby, 1967). It has been reported (Pena, 1967) that, in flooded taro, fertilizers increase yield by increasing the number and weight of the sucker corms; while in upland taro, fertilizers mainly cause an increase in the weight of the main corm. Nitrogen fertilizer results in an increased protein content of the corm, while potassium enhances efficient water use by the plant (Cable, 1975).

Fertilizer in taro should be applied as a split dose. The first application, made at planting, helps in the rapid development of the early leaves. The second application is made 3-4 months later in order to ensure rapid and normal enlargement of the corm. Since taro is normally grown under a regime of heavy water supply (rain or irrigation), applying the fertilizer in a single dose may result in excessive losses owing to leaching, so that the plant spends the latter part of the season in a low fertility situation. Splitting the fertilizer application is a partial solution to this problem.

Taro exhibits several symptoms when subjected to nutrient deficiencies. Potassium deficiency results in marginal chlorosis of the leaves. It also results in an increased respiration of the leaves and roots, and a decrease in leaf water content. The roots are apparently less resistant than the leaves to moderate potassium deficiency, and tend to die first (Okamoto, 1967, 1969). Zinc deficiency is characterized by inter-veinal chlorosis, stunting, narrow leaves, and cupping of the leaves (Lucas *et al.*, 1975). It has been suggested (Kagbo *et al.*, 1973) that, for phosphorus, a leaf petiole content below 0.23%, or soil content below 0.16 ppm, indicate the need to apply phosphorus fertilizer. It is noted, however, that under the reducing conditions of flooded taro culture, insoluble phosphorus may become available to the plants. Also, mycorrhizae may play a role in promoting phosphorus uptake.

18.9 FERTILIZING TANNIA

The nutritional requirements of tannia are less well known than those of taro. In Puerto Rico, the recommended rates of fertilization are 112 kg/hectare for nitrogen, 45 kg/hectare for phosphorus and 112 kg/hectare for potassium. Enyi (1968), on the other hand, obtained significant increases in yield by applying to each hectare 336 kg of ammonium sulphate plus 280 kg of superphosphate plus 224 kg of potassium sulphate. As with taro, a split application of fertilizer is best for tannia.

The nutrient deficiency symptoms of tannia are well known (Spence and Ahmad, 1967). Nitrogen deficiency causes stunted growth, small pale-green lamina, and short petioles. The same sort of symptoms are produced by lack of phosphorus, except that the colour of the leaves is unaffected. Potassium deficiency results in only a slight reduction in growth, but the older leaves show necrosis of the lamina tips and edges. Calcium deficiency is characterized by stunted growth, thick leathery older leaves, distorted young leaves with necrotic and chlorotic patches, and rapid senescence of the entire plant. Magnesium deficiency results in a bright-orange coloration between the veins. It begins near the leaf apex, spreads through the entire leaf, and eventually leads to rapid senescence of the leaf. Deficiencies of nitrogen, sulphur, and phosphorus result in smaller root systems; but the depression of corm growth is considerably less than that of top growth.

In traditional cocoyam cultivation in Africa and parts of the Pacific Islands, little or no fertilizers are used. This is particularly true when cocoyams are grown on land that has just been cleared from bush-fallow. On land that has been cropped for long periods, farmyard manure is sometimes placed in the planting holes.

18.10 CROPPING SYSTEMS FOR PRODUCING COCOYAMS

While the production of taro can occur under upland or flooded conditions, the production of tannia is confined almost exclusively to upland conditions. Most of the upland culture of taro and tannia is for subsistence. Average holdings are typically small, and intercropping is common. In Cameroon, (Agueguia, 1987) the major cocoyam-based cropping systems are:

a) In the very wet regions with a short dry season, the cocoyam is grown as a biannual or perennial crop. It is planted with little or no tillage and intercropped with maize and vegetables. Multiple harvesting of the cocoyam is practised, with mature cormels being removed from each cocoyam plant every three months or so, over a period of two or three years.

b) In the drier areas, the crop is grown as an annual, intercropped with vegetables and harvested at the onset of the first dry season.

c) In plantations of young cocoa, oil palm and rubber, cocoyam is sometimes grown as an intercrop until the plantation closes canopy.

In south-western Nigeria, tannia has historically been a favourite shade crop for young cocoa plants in plantations. On the other hand, cocoyams are among the favourite crops for compound gardens around homesteads in south-eastern Nigeria. Ash and refuse from the compound are used to provide nutrients for the cocoyams. Whether in compound gardens, or in more distant farms, intercropping with maize, yams, cassava, pulses, cucurbits, or ground-nut is quite common. Intercropping cocoyams with plantains and young oil palms is also practised. In Japan, upland taro and flooded rice are sometimes grown in rotation on the same plot, with a resultant improvement in yields of both crops.

The flooded cultivation of taro is a very specialized intensive cropping system found in Hawaii and Oceania. In this region, both flooded and upland cultivation of taro take place. The upland crop matures in about nine months, while flooded taro takes 12-18 months, but with higher yields. The overall aim in flooded taro cultivation is to have an integrated production system that will generate high-grade taro for human food, with taro tops and low-grade corms used for feed or alcohol production. This high-technology production of taro is strictly on a cash crop basis, and sole cropping is generally the rule. Monoculture, in which flooded taro is grown repeatedly on the same field for several years, is commonly practised. Such fields are occasionally dried and used to produce a crop of vegetables before returning to flooded taro.

Chapter 19

HARVESTING, STORAGE, DISEASES AND PESTS OF COCOYAMS

19.1 HARVESTING AND YIELDS

Cocoyams are ready for harvesting when most of the leaves begin to turn yellow. Apparently, there are no morphological changes indicating maturity, but physiological maturity corresponds to the time when sugars in the corm are at a minimum (Hashad *et al.*, 1956a).

The time from planting to harvesting varies with cultivar as well as the method of cultivation. In Hawaii, it is about 12 months for upland taro, and 15 months for flooded taro. Reported durations of taro in the field are 7-9 months in India, 7-11 months in the Philippines, 10-12 months in Fiji, and 6-8 months in Nigeria. In Trinidad, the dasheen types of taro require 8-10 months, while the eddoe types mature earlier, in 5-6 months.

Tannia is mature for harvesting in 9-12 months after planting. For both taro and tannia, no serious deterioration occurs if the crop is left in the ground for a few weeks after maturity. To some extent, therefore, harvesting may be done at the convenience of the farmer. For upland taro and tannia, harvesting should be timed to occur during the dry season, or at least during dry weather. At this time, most of the roots are dead so that the corms can be lifted merely by pulling. However, if rains occur after maturity, or harvesting is delayed too long, growth may resume, resulting in the production of new roots which make harvesting more difficult. Also, the resumed growth is at the expense of food stored in the corm and cormels; as such it tends to reduce the yield.

Most of the cocoyams grown in the world are harvested by hand or through the use of hand tools. In upland culture, pulling of the withered aerial portions of the plant is enough to lift the corms and cormels. However, the pulling may cause many of the cormels to be severed from the corm, and to remain in the ground. As an alternative to pulling, the crop may be ploughed out, followed by manual picking of the corms and cormels.

For flooded taro, the root system tends to remain alive, even after the crop is mature for harvesting. As such, it is not possible to lift the corms by pulling. Instead, a rod measuring 1.5-2 m is used to sever the roots in a circle around the plant. The corm is then prised from the soil.

Sometimes the entire cocoyam corm is not harvested at one time. Instead the soil is dug around the base of the main plant, and the cormels and secondary corms are removed, leaving the main corm or portions of it to continue growth and produce a new crop. When the new crop is mature, the same method of harvesting is used. In this way the crop is grown as a perennial, and is subjected to *multiple harvesting*. This practice is more common with tannia than with taro. It is most prevalent in regions of heavy year-round rainfall where the absence of a long dry season enables the plant to go from year to year without complete die-back of the aerial parts. The practice of multiple-harvesting in cocoyam is, to some extent, analogous to double-harvesting in yam, which has already been discussed. It shares the same disadvantages, particularly that of labour intensity. Whichever method of harvesting is adopted, it is important to avoid bruising the corms and cormels.

The hand labour required for cocoyam harvesting contributes to the high cost of the crop. It is hoped that, in future, some of the machinery now used to harvest other root crops, such as sweet potatoes and sugar beets, could be modified to harvest cocoyams. In some experiments with tannia in the West Indies, Gooding and Campbell (1961) found that the maximal depth of the corm and cormels was about 9 inches (23 cm), the maximal spread across the ridge was 17-19 inches (43-48 cm), and the maximal spread along the ridge was 19.6-20.9 inches (50-53 cm). When a yam harvester was used to harvest the crop, damage was 6.3-8.9% in comparison with 2.3% damage with hand harvesting.

Yields of cocoyams vary greatly from place to place, depending on the conditions under which they were produced, and the methods used for production. For taro, average yield on a world basis is about 5.3 tonnes/hectare. The highest yields (37-75 tonnes/ha) come from the intensive flooded cultivation of taro in Hawaii. Upland taro in the same area yields less than half as much. For tannia, yields of about 12 tonnes/hectare are considered good In Puerto Rico, yields of 25-37 tonnes/hectare have been reported.

19.2 STORAGE

Cocoyams can best be stored in cool, dry, well-ventilated surroundings. The best temperature for prolonged storage is about 7°C; at this temperature, tannia in Trinidad (Kay, 1973), and taro in Egypt (Hashad *et al.*, 1956b) did not deteriorate in storage for over 3.5 months. Storage at higher temperatures (e.g., 15-23 °C) is not satisfactory for long periods; while storage at lower, non-freezing temperatures (e.g., 2°C) results in death of the buds and decay of the corms within two months. A relative humidity of 85% has been recommended for cocoyam storage.

The storage of cocoyams in underground pits is common practice for taro in Egypt and Samoa, and for tannia in Cameroon. In other areas, cocoyams are often stored on open platforms in well-aerated surroundings. As has already been mentioned, cocoyams may be left in the ground after maturity, and harvested as needed. This provides field storage for the crop, and partly compensates for the poor ability of most types of cocoyam to store well for long periods.

Apart from storage as the fresh corms or cormels, cocoyams can be stored in dry processed or semi-processed forms.

19.3 DISEASES AND PESTS

19.3.1 **The root rot blight complex** or **Taro soft rot**

This is a major cocoyam disease in Africa and the Pacific Region. Taro soft rot disease has been reported in Hawaii, New Hebrides, and several other places in the Pacific area. In Hawaii, losses of 10-100% have been reported. The disease assumed considerable economic importance in West Africa in the 1980s, and has been a major threat to cocoyam production. The disease has been reported to attack tannia in Puerto Rico and New Caledonia.

The disease is caused by several species of *Phythium*. The pathogen is soil-borne and attacks the roots and corm. Infected plants show wilting and chlorosis of the leaves, as well as proliferation of roots at the base of the shoot. The corm becomes soft and smelly, and the plant is very stunted and often dies. Decaying plant parts on the field tend to favour the disease. The disease is more common in flooded taro, and relatively rare in upland taro.

Since taro soft rot can be carried in the planting material, one major control measure is to plant only disease-free material. Treatment of the soil and the planting material with Captan 50W at 112 kg/hectare has been recommended for non-alkaline soils. Captan is inactivated in alkaline soils and provides little control in such soils. Crop rotation is also effective in controlling soft rot. In Hawaii, varieties Kai Kea and Kai Uliuli have been found to be resistant to soft rot. In Cameroon, incidence of the disease could reportedly be reduced by wide spacing, high mounds, and adjustment of planting date (Caveness *et al*., 1987). Resistant clones have also been identified in breeding programmes in West Africa.

19.3.2 **Root-knot nematode (*Meloidogyne* spp.)**

This causes damage to upland taro, and may sometimes result in total loss of the crop. It causes characteristic galls to form on the roots, and irregular swellings of the corm; stunting of the plant also occurs. The disease can be carried in the corm and transmitted in the planting material. One control measure, therefore, is to plant nematode-free material. If the planting material is already infested, it can be treated with water above 40°C for 50 minutes in order to destroy the nematodes. Soil which is infested with root-knot nematodes should be fumigated with Telone, Nemagon, DDS, Hexanema, or Nemafos. Tannia reportedly is relatively resistant to the root-knot nematode.

19.3.3 **Dasheen mosaic virus disease**

This disease is caused by a stylet-borne virus carried by aphids. Symptoms include chlorosis, mosaic patterns on the leaves, leaf distortion, and stunting of the plant. The major control measure is the use and distribution of virus-free material. Such materials are readily produced through the use of meristem culture.

19.3.4 **Taro leaf blight**

This disease is caused by the fungus *Phytophthora colocasiae*. The disease first appears as purplish to brownish water-soaked circular foliar lesions from which a clear yellow liquid is exuded. The lesions are initially 1-2 cm in diameter. The lesions enlarge, coalesce, and eventually the entire lamina dies. Epidemics of the disease are favoured by nights with a temperature of 20-22°C and 100% relative humidity, and days with 25-28°C and 65% relative humidity, particularly if these conditions are accompanied by cloudy, rainy weather. Low temperatures (below 20°C) limit the sporulation of the fungus. Free water on the leaves is necessary for germination of the fungal spores, and for infection to occur. Under field conditions, young taro plants are not infected because their leaf lamina are almost vertical and do not retain appreciable amounts of free water. However, by the time the plants are 4.5 months old, lamina orientation is more nearly horizontal, so that water retention and infection occur readily. Moreover, overcrowding of foliage at this stage hinders air movement, keeps the humidity high, and thereby promotes spread of the disease. The disease is more severe in flooded than in upland taro.

The taro leaf blight disease was first reported in Java about 1900. Since then it has spread to all parts of the Pacific area; it has been reported in India, Hawaii, the Philippines, Australia, Japan, Formosa, Fiji, the Solomon Islands, China, the Caroline Islands, and the Mariana Islands. In Hawaii, losses attributable to the disease may reach 25-50%.

Taro leaf blight is most commonly controlled by the use of copper fungicides. In Papua New Guinea, weekly sprays of copper oxychloride have proved effective when spraying started 1-2 months after planting (Gollifer and Brown, 1974). In Hawaii, 0.4% tribasic copper sulphate has been used (Trujillo and Aragaki, 1964). Spraying is done every 12 days for four months, starting at five months after planting. Mancozeb (Diathane M45) at rates of 1-4 kg/hectare at intervals of 5-14 days has also proved effective (Bergquist, 1974). It is suggested that the farmer should avoid walking through the crop while spraying, since this encourages the disease.

Resistant varieties (e.g. variety Ahina) are the surest control measure. Tannia is not affected by this disease.

19.3.5 Sclerotium rot

Sclerotium rot is caused by *Sclerotium rolfsii*. This mainly occurs in upland taro as well as tannia. It causes stunting of the plant, rotting of the corm, and formation of numerous spherical sclerotia in the corm. White cotton-like mycelial growth is present. The disease has been reported in Fiji, the Philippines, and Hawaii. Control is by drenching the soil with Terraclor or Botran at the rate of 11-12 kg/hectare.

19.3.6 Cladosporium leaf spot

This is caused by *Cladosporium colocasiae*. This occurs in both flooded and upland taro. Dark-brown spots appear on the older leaves. The disease has been reported in Hawaii, New Caledonia, the New Hebrides, and Samoa. It does not cause appreciable yield losses, and is usually controlled incidentally when spraying is done to control taro leaf blight.

19.3.7 Insect pests

The **taro leafhopper** (*Tarophagus proserpina*) is the most serious insect pest of taro. It has caused severe losses in Hawaii, the Caroline Islands, and Samoa. Biological control has been achieved by using the Philippine egg-sucking bug (*Cyrtorhinus*). Other insect pests of taro are the **sweet potato hawk-moth**, whose larvae defoliate the plant, and the **taro beetle**, which feeds on the roots and corms of taro.

Chapter 20

UTILIZATION, SOCIO-ECONOMIC PERSPECTIVE AND FUTURE PROSPECTS

20.1 NUTRITIONAL VALUE OF TARO

The corm and cormels are the major economic parts of taro. Occasionally, the leaves and petioles are also used for food. The approximate composition of the taro corm on a fresh weight basis is as follows (Coursey, 1968; Oyenuga, 1968):

Moisture	63-85%
Carbohydrates (mostly starch)	13-29%
Protein	1.4-3.0%
Fat	0.16-0.36%
Crude fibre	0.60-1.18%
Ash	0.60-1.3%
Vitamin C	7-9 mg/100 g
Thiamine	0.18 mg/100g
Riboflavin	0.04 mg/100g
Niacin	0.9 mg/100g

The main stored food in the corm is therefore carbohydrate. The carbohydrate fraction of taro is composed as follows:

	%
Starch	77.9
Pentosans	2.6
Crude fibre	1.4
Dextrin	0.5
Reducing sugars	0.5
Sucrose	0.1

The starch of taro consists of 17-28% amylose, while the rest is amylopectin. The amylose has 490 glucose units per molecule while the amylopectin has 22 glucose units per molecule. The starch grains are very small, ranging in diameter from 1 to 4 m. As a result, taro starch is very readily digestible when used for food, but is unsuitable as a source of industrial starch.

The protein content of the taro corm (about 7% on a dry-weight basis) is slightly higher than that of yam, cassava, or sweet potato. The protein is rich in most of the essential amino-acids, but is rather low in histidine, lysine, isoleucine, tryptophan, and methionine.

All parts of the corm do not have exactly the same composition. The dry matter, as well as the starch content, of the corm are lower at the apex of the corm than at the base. In addition, most of the non-starchy nutrients of the corm are concentrated in the outer peel. The peels can therefore be utilized as feed for ruminants rather than being discarded. The corms of taro contain raphides. These are minute bundles of crystals of calcium oxalate (0.1-0.4% fresh weight), which account for the irritating effect of the raw corm. This effect is removed during boiling. Small quantities of cyanide are also present in the taro corm. The amount is much less than that present in cassava, and is not considered to be nutritionally hazardous. Taro, like sweet potato, contains small quantities of trypsin inhibitor. Tannia, yams and cassava do not have this characteristic (Bradbury & Holloway, 1988).

The leaf of taro is also nutritionally rich, containing about 23% protein on a dry-weight basis. It is a rich source of calcium, phosphorus, iron, Vitamin C, thiamine, riboflavin, and niacin. The leaf of taro is higher in protein than that of tannia, as well as in all the other nutrients except oil. The fresh taro leaf lamina contains 80% moisture, while the petiole has 94%.

There is increasing use of taro as a speciality food for potentially allergic infants, and for persons with gastro-intestinal disorders. Its small, readily-digestible starch grains make it suitable for this purpose.

20.2 NUTRITIONAL VALUE OF TANNIA

Tannia is nutritionally very similar to taro. The corm, cormels, and (sometimes) the leaves, are the main economically important parts of the plant. Generally the cormels are more tasty, and are preferred to the corms. The corm itself is composed of 77-86% edible material, and 14-23% scaly peel. The approximate composition of the tannia corm on a fresh weight basis is as follows.

Moisture	65-77%
Carbohydrate	17-26%
Protein	1.3-3.7%
Fat	0.2-0.4%
Dietary fibre	0.6-1.9%
Ash	0.6-1.3%
Carotene	2 mg/100 g
Thiamine	0.06 mg/100 g
Riboflavin	0.2 mg/100 g
Niacin	1 mg/100 g
Vitamin C	96 mg/100 g

The carbohydrate present in tannia consists mostly of starch. The starch has relatively large grains, the average diameter being 17-20 m. Tannia is therefore less readily digested than taro. Tannia is richer than taro in mineral elements but has approximately the same protein content. Like taro, the corms of tannia contain raphides, and should not be fed to humans or livestock without cooking.

The leaf of tannia can also be used for food; it is nutritionally very similar to taro leaves.

20.3 UTILIZATION OF TARO AND TANNIA

20.3.1 **Acridity in cocoyams**

Acridity and itchiness of raw cocoyams, when ingested or in contact with skin, is a major consideration in the utilization of taro and tannia. The acridity is reportedly greater if the crop has experienced adverse conditions such as drought or poor soil conditions. Acridity has usually been explained as being caused by physical puncturing of the skin by calcium oxalate crystals when they are released from the raphides. However, later evidence suggests that there is some chemical involvement (Bradbury & Holloway, 1988). Apparently, acridity only occurs when a chemical on the surface of the raphides interacts with the raphides.

20.3.2 **Fresh corms, cormels and leaves**

The corms and cormels of taro (see Figure 28) and tannia can be consumed after being boiled, baked, roasted, or fried in oil. In parts of West Africa, the boiled corms and cormels may be pounded into a paste, similar to pounded yam. The paste is swallowed in balls after being dipped in stew or soup.

As has already been mentioned, the leaves of taro and tannia can also be used for food. They are boiled before being eaten.

20.3.3 *Poi*

"Poi" is a processed form of taro which has become very popular in Hawaii and Polynesia. The corms and cormels of taro are first pressure-cooked, then they are washed, peeled, and mashed to a semi-fluid consistency. The product is then passed through a series of strainers, the final one having openings of 0.5 mm diameter. Next it is placed in bags, and sold or stored at room temperature. During storage the product undergoes fermentation owing to *Lactobacillus* spp. During this fermentation, the product becomes more acidic, the pH dropping from about 5.7 to 3.9. Coconut products may sometimes be added to the fermented "poi" before it is consumed.

20.3.4 **Flour**

For both tannia and taro, the fresh or precooked corms and cormels may be peeled, dried, and ground into flour. On a commercial scale, the flour is prepared by peeling the corms and cormels, slicing them, and washing them thoroughly with water to remove the adhering mucilage. The slices are then soaked overnight in water, washed again, then immersed in 0.25% sulphurous acid for three hours. After blanching in boiling water for 4-5 minutes, the slices are dried at 57-60°C. When thoroughly dry, they can then be milled into flour.

The use of cocoyam corms, cormels, and leaves as animal feed occurs to some extent, although it is not widespread.

20.4 PROBLEMS OF THE COCOYAM DELIVERY SYSTEM

Laboriousness. The production of cocoyams is labour intensive. Planting and harvesting require the most labour. Unfortunately most of the cocoyam production in the world is on small holdings where manual labour with hand tools is the method of production. The solution to the laboriousness of cocoyam production lies in greater mechanization. Efforts should be increased to devise machines that will plant and harvest the crop. It is hoped that seedling transplanters used for other crops can be modified for planting cocoyams. Harvesters of other root crops (e.g., sweet potato, sugar beet) may also be modified for harvesting cocoyam.

Limited ecology. The large quantity of water required to produce the cocoyam crop is a big problem, particularly in areas where water is scarce. The crop transpires a large amount of water per unit of dry matter produced, so that where water is costly, the farmer might prefer to grow some other crop which utilizes water more efficiently. Apart from the sheer quantities of water involved, cocoyam production requires that the water be available continuously throughout the growing season. The area of cocoyam production is therefore restricted to regions where rainfall (or irrigation water supply) is heavy and steady for several months of the year. This situation poses a serious restriction to the expansion of global cocoyam hectareage. The crop fails to do well in even moderately dry savanna areas.

Difficulty of breeding. The sexual processes in cocoyam are unreliable, and controlled hybridization is extremely difficult. The use of gibberellic acid to induce flowering has alleviated the problem somewhat, but much more progress still needs to be made.

Planting material. Like yams, but unlike cassava and sweet potato, cocoyams have the disadvantage that part of the edible harvest must be reserved as planting material. Up to 10% of the yield of corms is often reserved for subsequent use as planting material.

Storage. Most types of cocoyam do not keep well for long periods, and, in many instances, the farmer is tempted to leave them in the ground and harvest them as needed. Solutions to this problem will probably be found in on-going research aimed at devising cheap but efficient storage methods for cocoyams.

Diseases and pests. The diseases and pests of cocoyams, already discussed, pose serious problems in production. The more serious ones, such as the taro soft rot, have drastically limited production. Adequate control measures must not only be found; they must be effectively extended to the farmers.

20.5 SOCIO-ECONOMIC CHARACTERISTICS AND FUTURE PROSPECTS

20.5.1 Global production

The world production figures for cocoyams in 1990 are shown in Table 14. The main producing regions of the world are West Africa, Asia and Oceania. Nigeria, China and Ghana are the leading countries in production. However, the production in Oceania, though small in terms of the total, is highly significant. It is in this region, more than any other part of the world, that cocoyams attain their greatest importance as a food item. Per capita consumption is highest here. Cocoyams account for 18% of the food calories in Tonga, 16% in Samoa, and 7.7% in Solomon Islands (Table 3). In West Africa, the per capita production is highest in Cameroon, Ghana, and Gabon.

The world-wide trend in cocoyam production has been slightly downward over the 1980s (see Table 2).

20.5.2 Perspective and future prospects

Of the four major tropical tubers, cocoyams are the most obscure in many respects. Firstly the total area cultivated and tonnage produced are the least of the tropical tubers (see Table 1). Secondly, the average global yield per hectare is much lower than that of the other tuber crops. Thirdly, it is the most restricted in terms of the ecologies in which it can be grown. While yam, cassava and sweet potato can be cultivated both in the humid forests and in the drier savanna regions, cocoyam cultivation seems mostly confined to the high-rainfall humid regions. Fourthly, cocoyams have a low social status in most of the producing areas. Apart from Oceania and some localities in Ghana and Cameroon, cocoyam is not widely cultivated and consumed on a large scale. Cocoyams do not compete with yams in terms of food preference, and are also more expensive than cassava and sweet potato. Their cultivation often depends on how much labour and resources are left over from cultivating the other tuber crops; and their consumption becomes appreciable only when the other tubers are not available. Even then, there is little or no particular pride associated with cocoyam consumption.

Despite these shortcomings, there are a few redeeming factors that hold out promise for cocoyam as a crop of the future. Cocoyams appear to have certain characteristics which enable them to exploit ecological niches where other crops may fail or do poorly:

i) Some cultivars are tolerant to salinity, being able to grow in 25-50% sea water (Nyman & Arditti, 1984) . They can thus be used to reclaim saline soils.

ii) Cocoyams, especially taro, seem to possess the ability to tolerate water-logging, and could therefore be useful in hydromorphic soils.

iii) They can tolerate shading, and therefore prove useful in utilizing excess space and light when intercropped between plantation crops. Research is still needed however to characterize the extent of this shad tolerance, and to determine the extent to which cocoyams can be used on the plantation floor.

iv) Tannia has reportedly shown a high degree of resistance to the root-knot nematode (Caveness *et al*., 1987). It would therefore be a good crop to use to control nematode in a crop rotation system.

Of the major tropical tubers, cocoyams have received the least research attention. More research on this crop is needed in order to overcome various constraints hindering production development. Indeed, some modest research efforts devoted to cocoyams in the 1970s and 1980s were able to provide significant answers to some of the problems associated with the crop:

a) Regular flowering of cocoyams, hitherto extremely difficult, has been achieved by the use of gibberellic acid (Wilson 1979, 1980; Alvarez & Hahn, 1986). This technique has opened up the possibility of breeding through hybridization and recombination. It has resulted in the production of a large number of new genotypes available for selection.

b) The use of meristem tip tissue culture to produce virus-free plants has greatly enhanced international exchange of disease-free material. It has also made it possible to conserve large quantities of germplasm *in vitro*, rather than depending on the tedious and unreliable method of planting them out in the field.

c) A minisett technique, similar to that developed for yams, was fashioned for the rapid multiplication of planting material.

So much more needs to be done, that even modest investments in cocoyam research are expected to yield substantial progress.

APPENDIX I - TABLES

TABLE 1: WORLD AREA, YIELD AND PRODUCTION OF TUBERS IN 1990

	Area (x 1000 ha)	Yield (kg/ha)	Production (x 1000 tonnes)
Total	50215	11890	597071
Potato	17854	15098	269561
Cassava	15635	10084	157656
Yams	2928	10057	29447
Sweet Potato	11910	11058	131707
Cocoyams	983	5314	5225

Source: *FAO Prod. Yearbook Vol.44* for 1990. FAO, Rome, 1991

TABLE 2: CHANGE IN WORLD PRODUCTION OF TROPICAL TUBERS FROM 1979 TO 1989

	Production (x1000 tonnes)		
	1979-81	1989	%Change 1979-89
Cassava	124018	159122	+ 28.3
Yams	23394	28910	+ 23.6
Sweet Potato	134371	125039	- 6.9
Cocoyams	5638	5341	- 5.3

Source: *FAO Prod. Yearbook Vol. 44* for 1990. FAO, Rome 1991

TABLE 3: PERCENTAGE OF DIETARY CALORIES DERIVED FROM VARIOUS TUBERS IN 1984

	Per Capita Total Dietary calories	Sweet Potato	Cassava	Yams	Potato	Cocoyams	All Tubers
Zaire	2154	0.1	54.5	0.8	1.2	0.1	56.8
Tonga	2879	0.0	0.0	20.8	6.1	18.1	45.0
Cameroon	2089	0.0	6.3	30.7	1.5	0.5	44.5
Ghana	1747	0.0	26.2	10.0	0.0	7.1	43.3
Congo	2549	0.1	38.9	0.7	0.7	0.0	41.5
Mozambique	1678	0.4	40.0	0.0	0.5	0.0	41.0
Uganda	2083	1.0	25.8	0.0	12.8	0.0	39.6
Solomon Islands	2122	0.0	0.5	8.1	22.7	7.7	39.0
Gabon	2440	0.1	23.3	8.5	0.1	4.6	36.7
Benin	2173	0.0	21.3	12.8	0.9	0.3	35.4
Papua New Guinea	2181	0.1	3.2	4.6	14.2	4.2	32.6
Angola	1969	0.4	29.2	0.0	2.5	0.0	32.1
Rwanda	1919	3.6	8.1	0.1	17.6	0.6	30.0
Nigeria	2038	0.0	11.3	15.9	0.3	1.6	29.2
Togo	2236	0.0	17.0	11.1	0.2	0.7	29.1
Côte d'Ivoire	2505	0.2	7.0	16.8	0.0	1.4	25.6
Burundi	2116	0.5	8.5	0.2	12.6	2.5	24.2
Liberia	2311	0.0	19.7	0.9	0.8	0.7	22.1
Samoa	2433	0.1	0.3	0.6	0.0	16.0	19.2
Africa	2259	0.7	9.6	3.3	1.1	0.5	15.3
N. & C. America	3391	2.1	0.1	0.0	0.2	0.0	2.6
S. America	2627	2.3	3.7	0.1	0.3	0.0	6.4
Asia	2459	1.5	0.5	0.0	3.2	0.1	5.2
Europe	3406	4.7	0.0	0.0	0.0	0.0	4.7
Oceania	3166	2.9	0.6	0.6	1.6	0.7	7.2
World	2682	2.3	1.4	0.3	1.8	0.1	6.0

Source: After Horton (1988)

TABLE 4: COMPOSITION OF THE FRESH CASSAVA TUBER AND LEAVES

(Blanks indicate where no figures are available)

	Tuber	Leaves
Moisture, %	62	80
Carbohydrate, %	32-35	7
Protein, %	0.5-1.5	6
Fat, %	0.1-0.3	1
Crude fibre, %	1-2	2.5
Cyanide, mg/100g	1-100	18-180
Calcium, mg/100g	-	20-200
Iron, mg/100g	-	0.23-2.8
Vitamin B_1, mg/100g	-	0.2
Vitamin B_2, mg/100g	-	0.3
Vitamin C, mg/100g	35	80-200
Vitamin A, mg/100g	-	1-3
Niacin, mg/100g	-	1.5
Calories/100g	-	50
Ash, %	1	2.7

TABLE 5: WORLD PRODUCTION FIGURES FOR CASSAVA IN 1990

	Area (1000ha)	% World Area	Production (1000 tonnes)	% World Prod.	Yield (kg/ha)
World	15635	100	157656	100	10084
Africa	8932	57.1	73307	46.5	8207
S. America	2517	16.1	31766	20.1	12621
Asia	3965	25.4	51445	32.6	12974
Nigeria	1700	10.9	26000	16.5	15294
Brazil	1953	12.5	24611	15.6	12601
Thailand	1488	9.6	20701	13.1	13916
Zaire	2280	14.6	17500	11.1	7675
Indonesia	1398	8.9	17064	10.8	12206

Source: *FAO Prod. Yearbook Vol. 44* (for 1990). 1991 FAO, Rome

TABLE 6: ANNUAL GROWTH RATE (%) OF PER CAPITA PRODUCTION OF CASSAVA IN AFRICA

	1964-74	1974-84
West Africa	-0.8	-2.1
Central Africa	-3.0	-0.2
East Africa	-1.1	-0.2

Source: Dorosh, 1988

TABLE 7: PRODUCTION, LABOUR AND ENERGY YIELD FOR VARIOUS TROPICAL CROPS

	Labour (Persondays/ha)	Yield (tonnes/ha)	Energy Yield M cal/ha	Energy Yield M cal/ha/month
Cassava	180	9	12	1.1
Yams	300	8	7	0.8
Rice	200	2	5	1.0
Maize	80	2	8	1.8

TABLE 8: APPROXIMATE FOOD CALORIE PRODUCTION BY VARIOUS FOOD CROPS

Crop	Yield (tonnes/hectare)	Mcal/hectare	Approximate Mcal/hectare/month
Cassava	9	12	1.1
Yam	8	7	0.8
Sweet potato	7	7	1.6
Taro	6	6	1.4
Rice	2	5	1.0
Maize	2	8	1.8
Sorghum	1	3	0.8
Irish potato	10	6	1.4
Wheat	1	4	1.4

TABLE 9 COMPOSITION OF YAM TUBERS OF VARIOUS SPECIES.

(Blank spaces indicate where no figures are available)

	D. rotundata	*D. alata*	*D. cayenesis*	*D.esculenta*	*D. dumetorum*
Moisture (%)	60-70	70	80	70-80	80
Starch (%)	25-30	28	--	25	--
Sugars (%)	0.32	0.5	--	1-2	--
Fat (%)	0.1	0.1-0.3	0.1	0.1-0.3	0.3
Crude protein (%)	1.1-2.0	1.1-2.8	1.0	1.3-2.1	2.8
Crude fibre (%)	0.4-0.8	0.6-1.4	0.4	0.2-1.5	0.3
Ash (%)	0.7-2.6	0.7-2.1	0.5	0.5-1.2	0.7
Vitamin C (mg per 100 g)		6-12		5-28	5-820.3--
Vitamin B_1 (mg per 100 g)		--		0.09	--0.08--
Vitamin B_2 (mg per 100 g)		--		0.03	--0.02--
Vitamin A (mg per 100 g)		0.8		0.018	--0.017--

TABLE 10: RATIOS OF FRESH-WEIGHT YIELD:WEIGHT OF PLANTING MATERIAL (MULTIPLICATION RATIO) FOR VARIOUS CROPS

Crop	Approx. multiplication ratio
Maize	70
Guinea corn	80
Upland rice	20
Cowpea	25
Groundnut	15
Tannia	5
Taro	5
Irish potato	7
Yam	5

TABLE 11: THE WORLD'S LEADING YAM PRODUCERS IN 1990

	Area (1000 ha)	% of World Area	Production (1000 tonnes)	% of World Prod.	Yield (kg/ha)
World	2928	100	29447	100	10057
Nigeria	1900	64.9	22000	74.7	11579
Cote d'Ivoire	266	9.1	2528	8.6	9504
Benin	90	3.1	992	3.4	11026
Ghana	200	6.8	700	2.4	3500
Togo	40	1.4	420	1.4	10500
Zaire	38	1.3	270	0.9	7200
Africa	2789	95.3	28249	95.9	10127
West Indies	59	2.0	350	1.2	6122
Oceania	18	0.6	284	1.0	15818
Asia	15	0.5	198	0.6	12876

Source: *FAO Prod. Yearbook Vol. 44*

TABLE 12: ANNUAL GROWTH RATE (%) OF PER CAPITA PRODUCTION OF YAMS IN AFRICA

	1964-74	1974-84
West Africa	-0.3	-1.1
Central Africa	-1.2	-1.8

Source: Dorosh, 1988

TABLE 13: THE WORLD'S LEADING SWEET POTATO PRODUCERS IN 1990

	Area (1000ha)	% World Area	Production (1000 tonnes)	% World Prod.	Yield (kg/ha)
World	11910	100	131707	100	11058
Asia	10236	85.9	121885	92.5	11907
Africa	1208	10.1	6204	4.7	5137
South America	150	1.2	1538	1.2	10234
N & C America	191	1.6	1396	1.1	7295
Oceania	118	1.0	607	0.5	5121
Europe	6	0.1	77	0.1	12335
China	9112	76.5	112220	85.2	12316
Indonesia	241	2.0	2180	1.7	9046
Vietnam	340	2.8	2000	1.5	5882
Uganda	410	3.4	1670	1.3	4073
Japan	69	0.6	1450	1.1	21014
India	160	1.3	1300	1.0	8125

Source: *FAO Prod. Yearbook Vol. 44.*

TABLE 14: THE WORLD'S LEADING COCOYAM PRODUCERS IN 1990

	Area (1000ha)	% World Area	Production (1000 tonnes)	% World Prod.	Yield (kg/ha)
World	983	100	5225	100	5314
Africa	783	74.3	3130	59.9	3996
Asia	150	15.2	1727	33.1	11538
Oceania	47	4.8	337	6.4	7142
Nigeria	250	25.4	1300	24.9	5200
China	86	8.7	1182	22.6	13808
Ghana	200	20.3	900	17.2	4500
Japan	28	2.8	380	7.3	13571
Cote d'Ivoire	217	22.1	282	5.4	1300
Papua New Guinea	32	3.2	215	4.1	6719

Source: *FAO Prod. Yearbook Vol. 44.*

APPENDIX II - FIGURES

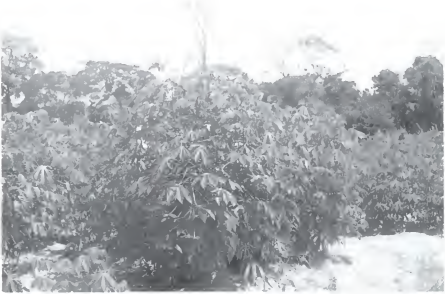
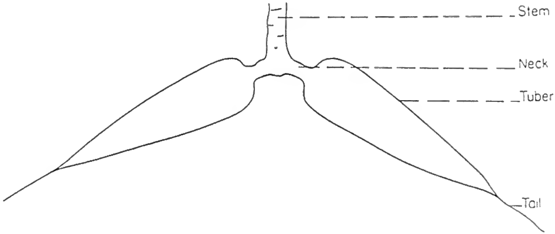


Figure 1. Growth habit of cassava

Figure 2. General morphology of the cassava tuber



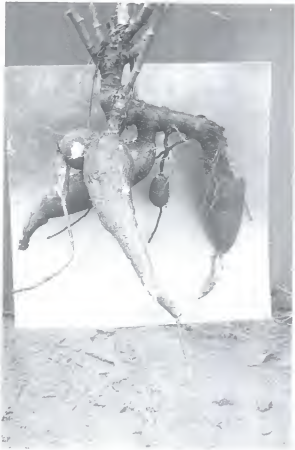


Figure 3. Cassava tubers

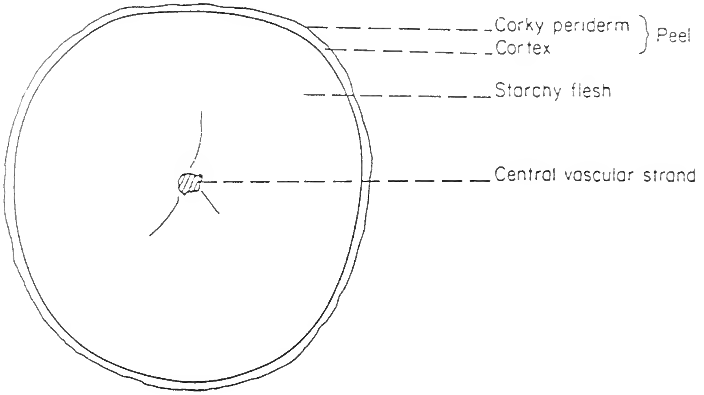


Figure 4. Transverse section of the cassava tuber

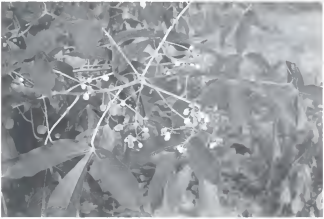


Figure 5. Inflorescence of cassava

Figure 6. Cassava chips for human consumption

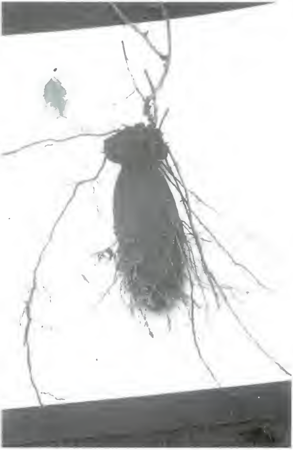


Figure 7. The yellow yam, *Dioscorea cayenensis*

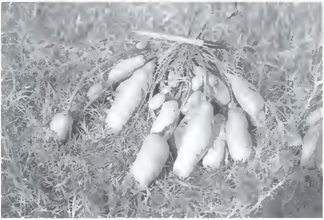


Figure 8. *Dioscorea esculenta*

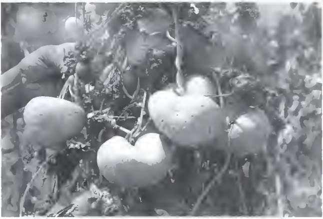
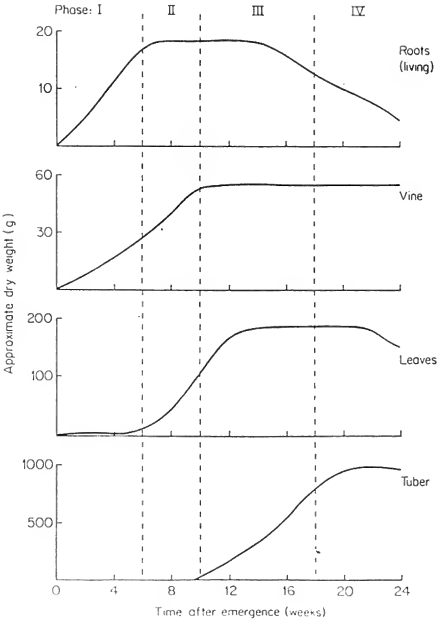


Figure 9. Bulbils of *Dioscorea bulbifera*

Figure 10. Phases in the yam growth cycle



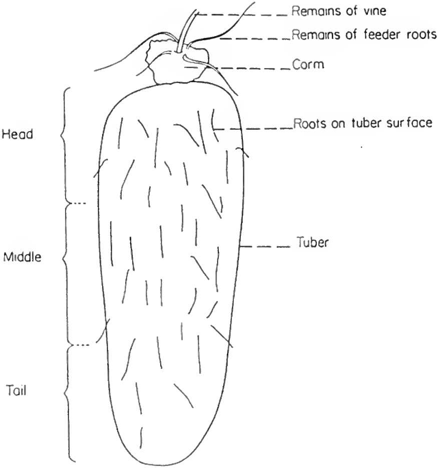


Figure 11. Yam tuber morphology

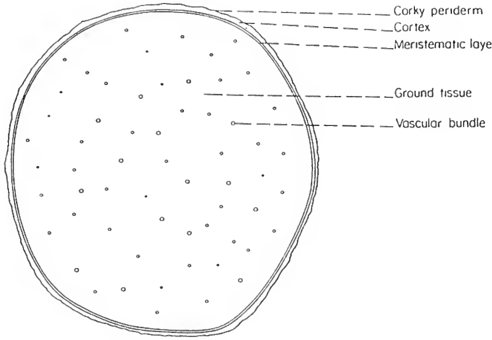


Figure 12. Transverse section of the yam tuber

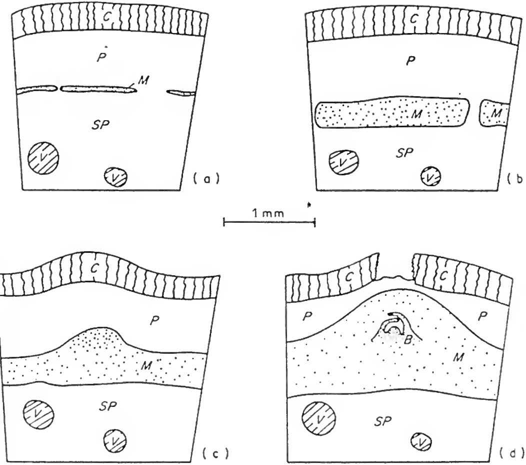


Figure 13. Four stages (a, b, c, d) in the sprouting of the yam tuber. B, newly differentiated bud; C, cork layer; M, layer of meristematic cells; P, parenchyma cells with very little stored starch; SP, storage parenchyma with much stored starch; V, vascular bundles; (after Onwueme, 1973)

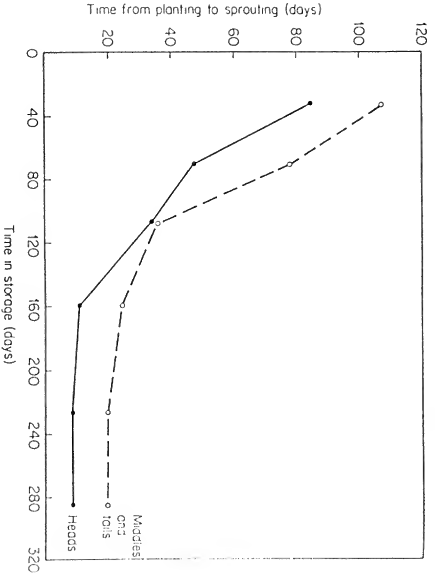


Figure 14. Effect of duration in storage on the time required for the yam tuber to sprout (adapted from Onwueme, 1975a)

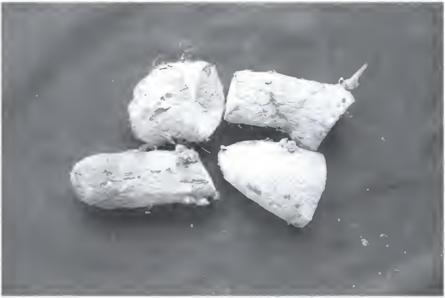


Figure 15. Setts of *Dioscorea alata* after dry presprouting

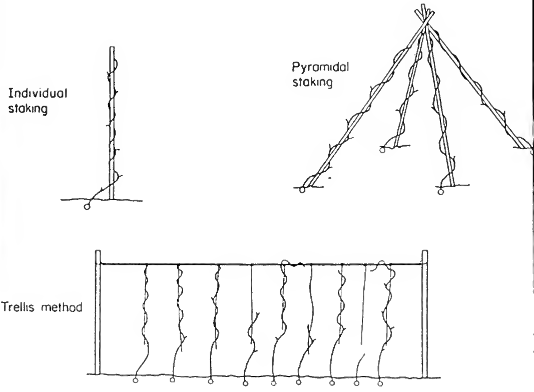


Figure 16. Methods of staking yams

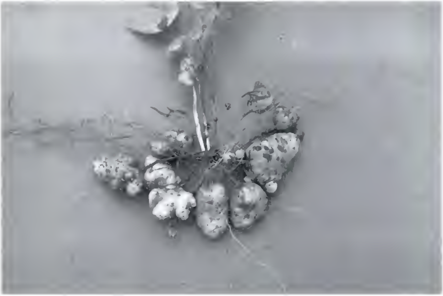


Figure 17. *Dioscorea esculenta* tubers showing root knot nematode damage

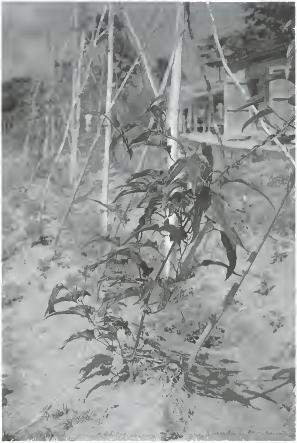


Figure 18. Yellow yam infected with the shoe-string virus disease.

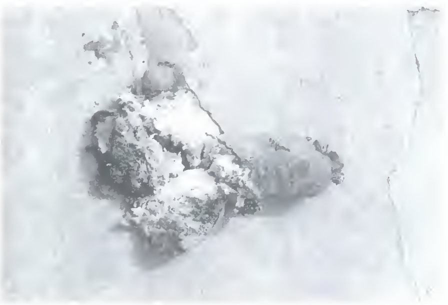


Figure 19. Soft rot of yam

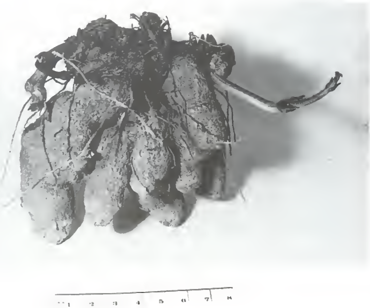
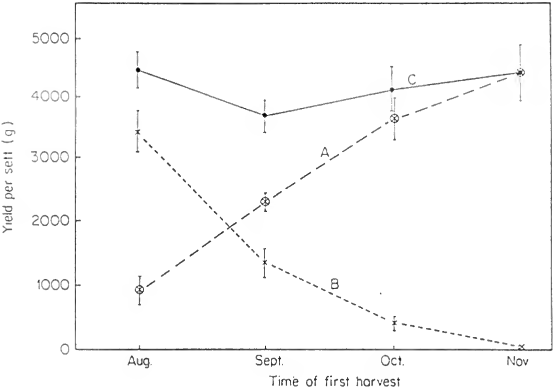


Figure 20. Yam tuber from the second harvest

Figure 21. Effect of timing of the first harvest on the yield of the second harvest of yams. The later the first harvest (A), the lower the yield of the second harvest(B). C indicates the sum of the yields from the first and second harvests (after Onwueme, 1977b)



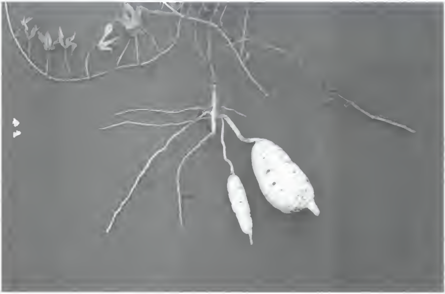


Figure 22. Stages of tuber formation in sweet potato

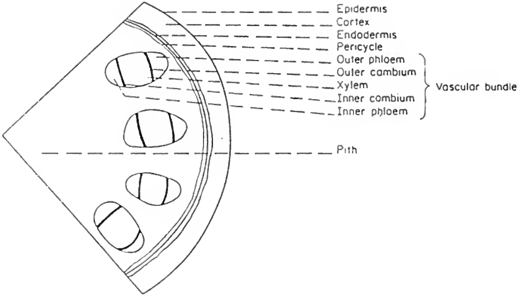


Figure 23. Transverse section of the sweet potato stem

Figure 24. Planting sweet potato on ridges

Figure 25. Taro in the field

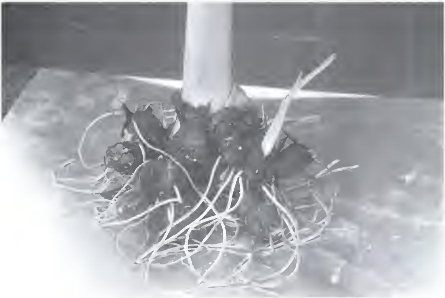


Figure 26. Corms and cormels of taro

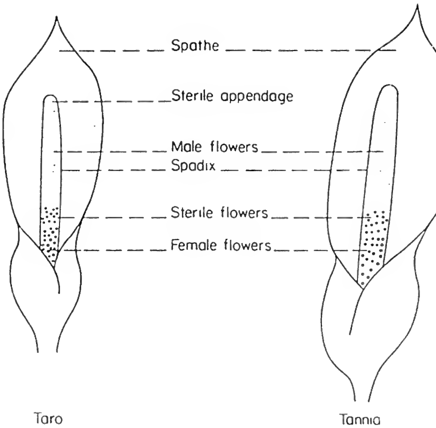


Figure 27. Structure of the inflorescences of taro and tannia. The spathe has been opened up to display the spadix in each case

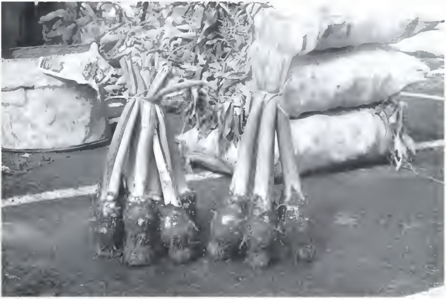


Figure 28. Taro (dalo) bundled for sale in Fiji

REFERENCES

Adamson, I., and Abigor, R. (1980) Transformation associated with catecholase in *Dioscorea alata* during storage. *Phytochemistry* **19**: 1593-1595.

Adesuyi, S.A. (1973) Advances in yam storage research in Nigeria, *3rd Int. Symp. Trop. Root Crops*, Ibadan, Nigeria.

Adrian, J., Pyrot, F., Oliveira, J.S., and Carvalho, M.F. de (1969) Nutritional study of cassava leaf (*Manihot utilissima*), *Rev. Cienc. Agron. Ser. A.*, **2**: 43-59.

Agueguia, A. (1987) Constraints of cocoyam (*Xanthosoma sagittifolium* L.) cultivation in Cameroon. In: Arene, O.B., Ene, L.S.O., Odurukwe, S.O., & Ezeh, N.O.A., (Ed.) *Cocoyams in Nigeria*. NRCRI, Umudike, Nigeria.

Alagianagalingam, M.N. and Ramakrishnan, K. (1970) Studies on a virus disease of tapioca (*Manihot esculenta* Crantz) 2. Carbohydrate metabolism, *Madras agric. J.*, **57**: 55-62.

Alvarez, M.N. & Hahn, S.K. (1986) Seed production in sweet potato, yam and cocoyam at IITA. In: Cock, J.H. (Ed) *The proceedings of the global workshop on root and tuber crops propagation;* 13-16 Sept., 1983. Cali, Colombia. CIAT, Cali, Colombia.

Asumugha, G.N., & Obiechina, C.O.B. (1991) Farm-level comparative economics of minisett and traditional yam production technologies in Imo State of Nigeria. *Proc. 9th Symp. Int. Soc. Trop. Root Crops*. Accra, 1991.

Atu, U.G. & Onwueme, I.C. (1991) Effects of seed dressing pesticides on stored, cut yam setts for pre-sprouting. *Proc. 9th Symp. Int. Soc. Trop. Root Crops*, Accra, 1991.

Averre, C.W. (1967) Vascular streaking of stored cassava roots, *1st Int. Symp. Trop. Root Crops,* St. Augustine, Trinidad.

Ayensu, E.S. (1972) *Anatomy of the Monocotyledons VI Dioscoreales*, Oxford University Press.

Babasana, H., Doulou, V. (1989) The political, economic, and social aspects of the production and consumption of roots, tubers and legumes in Africa - illustrated by the example of the Congo. In: *Roots, Tubers and Legumes.* DSE, Feldafing, Germany.169pp.

Bates, W.N. (1963) *Mechanization of tropical crops,* Temple Press, London.

Beck, B.D. (1960) Cassava trials on Moor Plantation, *Rep. Dept. Agric. Res., Nigeria, 1958-59.*

Bolhuis, G.G. (1966) Influence of length of the illumination period on root formation in cassava *M. utilissima* Pohl, *Neth. J. Agric. Sci.*, **14**: 251-262.

Bourke, R.M., Evenson, J.P. & Keating, B.A. (1984) Relationship between the altitudinal limit of cassava and soil temperature in Papua New Guinea. *Tropical Agriculture (Trinidad)* **61**: 315-316.

Bradbury, H.J. and Holloway, W.D. (1988) *Chemistry of tropical root crops*. ACIAR, Canberra. 201pp.

Brown D.H. (1931) The cultivation of yams, *Trop. Agric., Trin.,* **8**: 201-206; 231-236.

Budelman, A. (1991) *Woody species in auxiliary roles: live stakes in yam cultivation*. Royal Tropical Institute, Amsterdam. 151pp.

Burkhill, I.H. (1960) Organography and evolution of Dioscoreaceae, the family of yams, *J. Linn., Soc. (Bot.).,* **56**: 319-412.

Cable, W.J. (1975) Potassium requirement of taro *Colocasia esculenta* (L.) Schott in solution culture. *Trop. Root Tuber Crops Newsletter* 8: 39-40

Campbell, J.S. and Gooding, H.J. (1962) Recent development in the production of food crops in Trinidad, *Trop. Agric., Trin.,* **30**: 261-270.

Campbell, J.S., Chukueke, V.O., Teriba, F.A., and Ho-A-Shu, H.V.S. (1962a) Some physiological investigations into the White Lisbon Yam (*Dioscorea alata* L.). 1. The breakage of the rest period in tubers by chemical means. *Emp. J. Exp. Agric.,* **30:** 108-114.

Campbell, J.S., Chukueke, V.O., Teriba, F.A., and Ho-A-Shu, H.V.S. (1962b) Some physiological investigations into the White Lisbon Yam (*Dioscorea alata,* L.). 2. Growth period and out of season production. *Emp. J. Exp. Agric.,* **30:** 232-238.

Campbell, J.S., Chukueke, V.O., Teriba, F.A., and Ho-A-Shu, H.V.S. (1962c) Some physiological experiments with White Lisbon yam (*Dioscorea alata* L.) in Trinidad. 3. Effect of chemicals on storage, *Emp. J. Exp. Agric.,* **30:** 335-344.

Caveness, F.E., Hahn, S.K., Alvarez, M.N., & Ng, S.Y. (1987) The cocoyam improvement program at IITA., 1973-87. In: Arene, O.B., Ene, L.S.O., Odurukwe, S.O., Ezeh, N.O., (Eds.), *Cocoyams in Nigeria*. NRCRI, Umudike, Nigeria, 1987.

Chant, S.R. (1959) A note on the inactivation of mosaic virus in cassava (*Manihot utilissima* Pohl.) by heat treatment, *Emp. J. Exp. Agric.,* **27:** 55-58.

Chapman, T. (1965) Some investigations into factors limiting yields of the White Lisbon yam (*Dioscorea alata* L.) under Trinidad conditions, *Trop. Agric., Trin.,* **42:** 145-151.

Ching, K.W. (1970) Development of starch, protein, leaf and corm in *Colocasia esculenta.Proc. 2nd Int. Symp. Trop. Root & Tuber Crops* **1**: 143-146.

Chinwuba, P.M. (1971) Review of yam production in Nigeria during the last ten years, *Root Tuber Crops Symp.,* Ibadan, Nigeria.

C.I.A.T. (Centro International de Agricultura Tropical, Cali, Colombia) (1973) *Annual Report 1972.*

C.I.A.T. (Centro International de Agricultura Tropical, Cali, Colombia) (1975) *Annual Report 1974.*

C.I.A.T. (Centro International de Agricultura Tropical, Cali, Colombia) (1976) *Annual Report 1975.*

Cock, J.H. & El-Sharkawy, M.A. (1988) The physiological response of cassava to stress. *Proc. 7th Smp. Int. Soc. Trop. Root Crops*, Guadeloupe,1985. Ed. INRA, Paris. pp 451-462.

Cours, G. (1951) *(Manioc in Madagascar), Mem. Inst. Sci. Madagascar, Ser. B, III, Fasc. 2.*

Cours, G. *et al.* (1959) The phelloderm diagnosis of cassava, *Bull. 3 Inst. Rech. Agron. Madagascar,* **1959,** 22-23.

Coursey, D.G. (1965) The role of yams in West African food economies, *World Crops*, **17:** 74-82.

Coursey, D.G. (1968) The edible aroids. *World Crops* **20**: 25-30.

Coursey, D.G. (1967) *Yams.* Longmans, London, 230pp.

Coursey, D.G. and Aidoo, A. (1966) Ascorbic acid levels in Ghanaian yams, *J. Sci. Food Agric.*, **17,** 46-449.

Coursey, D.G., and Walker, H.M. (1960) A study of the origins of weight losses in stored yams, *Rep. W. Afr. Stored Prod. Res. Unit,* 1960, pp 61-64.

de Bruijn G.H. (1971) A study of the cyanogenetic character of cassava (*Manihot esculenta* Crantz), *Mededelingen Landbauwhogeschool Wageningen*, 140 pp.

de Bruijn G.H. and Fresco, L.O. (1989) The importance of cassava in world food production. *Neth. J. Agric. Sci.* **37**: 21-34.

Diehl, L. (1981) *Smallholder farming systems with yam in the Southern Guinea Savanna of Nigeria.* GTZ, Eschborn, Germany.

Doll, J., Piedrahita, W. (1973) Some factors of weed control in cassava, *3rd Int. Symp. Trop. Root Crops,* Ibadan, Nigeria.

Dorosh, P. (1988) The economics of root and tuber crops in Africa. *RCMP Research Monograph,* IITA, Ibadan, Nigeria.

Edmond, J.B., and Ammerman, G.R. (1971) *Sweet potatoes; Production, Processing, Marketing,* Avi Publishing Co., Westport, USA, 334 pp

Edmond, J.B. *et al.* (1950) Cooperative studies on the effects of height of ridge, nitrogen supply, and time of harvest on yield and flesh colour of the Puerto Rico sweet potato, *U.S. Dept. Agric. Circ. 832.*

Ekandem, M.J. (1970) Technique for cassava hybridization and production of seedlings, *Fed. Dept. Agric. Res., Nigeria, Memo No. 105.*

El-Sharkawy, M.A., Cock, J.H., & Porto, M.C.M. (1989) Caracteristicas fotossinteticas da mandioca (*Manihot esculenta* Crantz). [Photosynthetic characteristics of cassava] *Revista Brasileira Vegetal* **1**: 143-154.

Enyi, B.A.C. (1968) Growth of cocoyam (*Xanthosoma sagittifolium* Schott) *Indian J. Agric. Sci.* **38**: 627-633

Enyi, B.A.C. (1970) The effect of age on the establishment and yield of cassava setts (*Manihot esculenta* Crantz), *Beitr. Trop. Subtrop. Landwirt Tropenvet. Med.*, **8:** 71-75.

Enyi, B.A.C. (1973) Growth, development, and yield of some tropical root crops, *3rd Int. Symp. Trop. Root Crops*, Ibadan, Nigeria

Ezumah, H.C. & Plucknett, D.L. (1973) Response of taro, *Colocasia esculenta* (L.) Schott, to water management, plot preparation and population. *Proc. 3rd Int Symp. Trop. Root Crops*, Ibadan, Nigeria.

F.A.O. (Food and Agriculture Organization of the United Nations) (1986) Role of roots, tubers and plantains in food security in sub-Saharan Africa. *FAO Committee on world food security, 11th session*, Rome, 1986.

F.A.O. (Food and Agricultural Organization of the United Nations) (1991) *Production Yearbook Vol. 44 (for 1990)*

F.A.O. (1991) *Food outlook, December, 1991.* FAO, Rome.

F.D.A.R. (Federal Department of Agricultural Research, Ibadan, Nigeria) (1966) *Annual Report 1958*

Ferguson, T.U. (1972) The propagation of yams by vine cuttings; a critical review, *Trop. Root Crops Newsletter*, No. 5:4.

Ferguson, T.U. (1973) Tuber development in yams: physiological and agronomic implications, *3rd Int. Symp. Trop. Root Crops*, Ibadan, Nigeria.

Fukai, S. (1985) Tabular descriptions of crops grown in the tropics. 5. Cassava (*Manihot esculenta* Crantz). *Technical Memo 85/3.* CSIRO, Canberra. 51pp.

Gollifer, D.E. & Brown, J.F. (1974) Phytophthora leaf blight of *Colocasia esculenta* in the British Solomon Islands.*Papua New Guinea Agric. J.* 25: 6-11

Gonzalez, M.A., and Rivera, A.C. de (1972) Storage of fresh yam (*Dioscorea alata* L.) under controlled conditions, *J. Agric. Univ. Puerto Rico,* **56:** 46-56.

Gregory, L.E. (1968) in *J. Agric. Univ. Puerto Rico.,* **52:** 155-163.

Gurhan, A.M. (1974) Effects of method of planting and the length and types of cuttings on yield and some yield components of cassava (*Manihot esculenta* Crantz) grown in the forest zone of Ghana, *Ghana J. Agric. Sci.* **7:** 103-108.

Hahn, S.K., Bai, K.V., Asiedu, R., & Dixon, A.G.O. (1991) Polyploid breeding of cassava. *9th Symp. Int. Soc. Trop. Root Crops.* Accra, 1991.

Hashad, M.N. *et al.* (1956a) Transformation and translocation of carbohydrates in taro plants during growth. *Ann. Agric. Sci. Fac. Agric. Ain Shams Univ. Cairo* 1: 261-267.

Hashad, M.N. *et al.* (1956b) Transformation of carbohydrates in taro corms during storage. *Ann. Agric. Sci. Fac. Agric. Ains Shams Univ. Cairo* 1: 269-276.

Hassan, F.M. El (1966) The effect of controlled atmospheres on the keeping quality of sweet potatoes, *Diss. Abstracts,* **27:** 650B-651B.

Horton, D. (1988) *Underground crops: Long-term trends in production of roots and tubers*. 132pp Winrock International, USA.

Hozyo, Y., and Kato, S. (1976) Thickening growth inhibition and re-thickening growth of tuberous roots of sweet potato plants (*Ipomoea batatas*), *Proc. Crop. Sci. Soc. Japan*, **45:** 131-138.

Hua, H.T. (1970) Studies on some major pests of sweet potatoes and their control, *Malay. Agric. J.,* **47:** 437-452.

Hayward, L.A.W., and Walker, H.M. (1961) The effect of pre-harvest foliar spraying with maleic hydrazide on storage of yam, *Rep. W. Afr. Stored Prod. Res. Unit,* 1961, pp107-115.

Hill, W.A., Bonsi, C.K., Loretan, P.A., Morris C.E., Pace, R.D., & Lu, J.Y. (1988) Sweet potato for space missions: a new approach for marketing. *Proc. 8th. Symp. Int. Soc. Trop. Root Crops* (Bangkok), 609-614.

IITA (International Institute of Tropical Agriculture, Ibadan, Nigeria) (1971) *Annual Report, 1971.*

IITA (International Institute of Tropical Agriculture, Ibadan, Nigeria) (1972) *1972 Report, Root, tuber, and vegetable improvement program.*

IITA (International Institute of Tropical Agriculture, Ibadan, Nigeria) (1973) *1973 Report, Root and tuber improvement program.*

IITA (International Institute of Tropical Agriculture, Ibadan, Nigeria) (1974) *Annual Report, 1974.*

IITA (International Institute of Tropical Agriculture, Ibadan, Nigeria) (1975) *IITA Letter No. 6.*

IITA (1985) Farming systems research program - research highlights, 1981-84. Ibadan, Nigeria.

IITA (1988) IITA strategic plan 1988-2000. IITA, Ibadan, Nigeria

Ikemoto, S. (1971) Studies on direct planting of sweet potato, *Bull Chugoku National Agric. Exp. Stat. No. 20,* 117-156.

Indira, P., and Kurian, T. (1973) A comparative study of the anatomical changes associated with tuberization in roots of cassava and sweet potato, *3rd Int. Symp. Trop. Root Crops, Ibadan, Nigeria.*

Indira, P., and Sinha, S.K. (1970) Studies on the initiation and development of tubers in *Manihot esculenta* Crantz, *Indian J. P. Physiol.*, **13:** 24-39.

Ireland, C.R., Schwabe, W.W. & Coursey, D.G. (1981) The occurrence of batatasins in the Dioscoreaceae. *Phytochemistry* **20**: 1569-1571.

Iswaran, V., and Conty, A. (1974) The relative efficiency of soil and foliar application of urea-phosphorus mixture on the yield of sweet potato (*Ipomoea batatas*) var. BNAS, *Philippine J. Plant Industry,* **39:** 163-170.

Jacoby, T. (1967) Nutrition and manuring of tropical root crops. *Green Bull.* **19**: 31

Jennings, D.L. (1970) Cassava in Africa, *Field Crop Abstracts*, **23:** 271-278.

Jones, W.O. (1959) *Manioc in Africa*, Stanford University Press, Stanford, 315 pp.

Kagbo, R.S., Pena, R.S. de la, Plucknett, D.L. & Fox, R.L. (1973) Mineral nutrition of taro (*Colocasia esculenta*) with special reference to phosphorus. *Proc. 3rd Int. Symp. Trop. Root Crops*, Ibadan, Nigeria.

Kanno, H., Hahn, S.K., Dixon, A.G.O., & Asiedu, R. (1991) Mechanisms of resistance to green spider mite in some IITA improved cassava clones. *Proc. 9th Symp., Int. Soc. Trop. Root Crops*, Accra, 1991.

Karnjanakorn K. (1968) Planting positions and weed control in cassava plantations at Si Racha, *Dissertation, Kasetsart University, Thailand*.

Kasasian, L., and Seeyave, J. (1967) Weed control in root crops grown in the West Indies, *Proc. 2nd Int. Symp. Trop. Root Crops*, **2:** 20-25.

Kay, D.E. (1973) *Crop and Product Digest 2: Root Crops*. Tropical Products Institute, London. 245pp.

Kimber, A.J. (1970) Some cultivation techniques affecting yield response in the sweet potato, *Proc. 2nd Int. Symp. Trop. Root Tuber Crops, Honolulu*, **1**, 32-44.

King, G., and Hackett, C. (1986) Tabular descriptions of crops grown in the tropics. 13 Greater yam (*Dioscorea alata* L.). CSIRO, Canberra. 53pp.

King, G., and Hackett, C. (1986) Tabular descriptions of crops grown in the tropics. 14. Lesser yam (*Dioscorea esculenta*, (Lour.) Burk.) CSIRO, Canberra. 52pp

Krochmal, A. (1966) Lahour input and mechanization of cassava, *World. Crops,* **18:** 28-30.

Krochmal. A. (1969) Propagation of cassava, *World. Crops,* **21:** 193-195.

Krochmal, A., and Samuels, G. (1968) Deficiency symptoms in nutrient pot experiments with cassava, *Ceiba*, **14**, 7-11.

Lal, R., and Hahn, S.K. (1973) Effect of method of seed bed preparation, mulching, and time of planting on yam (*Dioscorea rotundata*) in Western Nigeria, *3rd Int. Symp. Trop. Root Crops*, Ibadan, Nigeria.

Lawton, J.R., and Lawton, J.R.S. (1969) The development of the tuber in seedlings of five species of *Dioscorea* from Nigeria, *Bot. J. Linn. Soc.,* **62:** 223.

Leihner, D. (1983) *Management and evaluation of intercropping systems with cassava*. CIAT, Cali, Colombia. 70pp.

Lozano, J.C. and Booth, R.H. (1973) The super elongation disease of cassava, *3rd Int. Symp. Trop. Root Crops*, Ibadan, Nigeria.

Lucas, R.J., Punu, B. & Cable, W.J. (1975) Aspects of taro production in the shallow calcareous soils of Nuie. *Trop. Root Tuber Crops Newsletter* **8**: 40

Lyonga, S.N., Fayemi, A.A., and Agboola, A.A. (1973) Agronomic studies on edible yams (*Dioscorea* spp.) in the grassland plateau region of the United Republic of Cameroon, *3rd Int. Symp. Trop. Root Crops*, Ibadan, Nigeria.

Makanjuola, G.A., Onochie, B.E., and Schulte, E.E. (1973) Preliminary studies on the mechanical harvesting of cassava roots in Nigeria, *3rd Int. Symp. Trop. Root Crops,* Ibadan, Nigeria.

Malavolta, E. *et al.* (1955) Studies on the mineral nutrition of cassava (*Manihot utilissima* Pohl), *Plant Physiol.,* **30:** 81-82.

Mapes, M.O. (1973) Mericloning of taro varieties, *Colocasia esculenta* (L.) Schott. *Proc. 3rd Int. Symp. Trop. Root Crops,* Ibadan, Nigeria.

Mann, W.S. (1963) Fertilizer use in Eastern Nigeria, *Tech. Bull. No. 5,* Eastern Nigeria Ministry of Agriculture.

Martin, F.W. (1974) Selected yam varieties available for distribution, *Memo. Fed. Exp. Sta., Mayaguez, Puerto Rico.*

Martin, F.W., and Ortiz, S. (1963) Origin and anatomy of tubers of *Dioscorea floribunda* and *D. spiculiflora, Bot. Gaz.,* **124:** 416-421.

Martin F.W., Cabanillas, E., and Ruberte, R. (1974a) Yam-1974 Program, progress, plans, *Memo Fed. Exp. Sta., Mayaguez, Puerto Rico.*

Martin, F.W. Koo, F.K.S., and Cuevas, J. (1974b) Stimulation of yam (*Dioscorea*) tuber growth by gamma irradiation. *J. Am. Soc. Hort. Sci.* **99:** 282-284.

Martin, F.W. and Splittstoesser, W.E. (1975) A comparison of total protein and amino acids of tropical roots and tubers, *Trop. Roots Tuber Crops Newsletter,* **8:** 7-15

Miege, J. (1954) Nombres chromosomiques et répartition géographique de quelques plantes tropicales et équatoriales, *Rev. Cytol. Biol. Veg.,* **15:** 312-348.

Miege, J. (1965) Influence de quelques caractères des tubercules semences sur la levée et le rendement des ignames cultivées, *J. Agric. Trop. Bot., Appl.,* **4:** 315-342.

Mogilner, I., Orioli, G.A., and Blettler, C.M. (1967) Trial to study topophysis and photoperiodism in cassava, *Bonplandia,* **2:** 265-272.

Morita, T. (1969) Effect of nitrogen sources on the top growth, tuber formation, and its development in sweet potato, *J. Japan Soc. Hort. Sci.,* **38:** 163-168.

Moursi, M.A. (1954) A comparative physiological study of Dasheen (*Colocasia antiquorum* (Schott). *Indian J. Hort. Sci.* 11:74.

Murant, A.F., Roberts, I.M., and Jennings, D.L. (1973) Electron microscopy of cassava leaves with African cassava mosaic, *3rd Int. Symp. Trop. Root Crops,* Ibadan, Nigeria.

Narasimhan, V., and Arjunan, G. (1973) Effect of mosaic disease on cassava *3rd Int. Symp. Trop. Root Crops,* Ibadan, Nigeria.

Neuenschwander, P., Hammond, W.N.O., and Herren, H.R. (1987) Biological control of the cassava mealy bug (*Phenacoccus manihoti*) by the exotic parasitoid, *Epidinocarsis lopezi.* In: Terry, E.R., Akoroda, M.O., & Arene, O.B. (Ed.) *Tropical Root Crops: Root crops and the African food crisis.* (Proc. 3rd Triennial Symp. Int. Soc. Trop. Root Crops - Africa Branch, Owerri, Nigeria, 1986) IDRC, Ottawa.

Ng, S.Y.C., (1991) Virus-free yam (*Dioscorea rotundata* Poir): distribution methods. *Proc. 9th Symp. Int. Soc. Trop. Root Crops,* Accra. 1991.

Ngongi, A.G., Howeler, R.H., and MacDonald, H.A. (1976) Effects of potassium sources and rates of application on growth, yield and composition of cassava (*Manihot esculenta* Crantz) *4th Symp. Trop. Root Crops,* Cali, Colombia.

Nielsen, L.W. (1967) Relationship of storage temperature, fungicides and varietal resistance to the infection of sweet potato roots by the *Fusarium* wilt fungus. *Phytopathology*, **59:** 508-510.

Ninan, C.A., Abraham, S., Bia, L.A., Niar, P.N., and Kuriachen, A. (1976) Lipid metabolism in cassava mosaic infested *Manihot esculenta* Crantz, *4th Symp. Trop. Root Crops,* Cali, Colombia, 1976.

Njoku, E. (1963) The propagation of yams (*Dioscorea* spp.) by vine cuttings, *J. W. Afr. Sci. Ass.,* **8:** 29-32.

Normanha, E.A., and Pereira, A.S. (1950) Agronomic aspects of cassava growing, *Bragantia*, **10:** 179-202.

Nwankiti, A.O. & Okpala, E.U. (1981) Anthracnose of water yam. In: Terry, E.R., Oduro, K.A., & Caveness, F. (Ed.) In: *Tropical root and tuber crops: research strategies for the 1980s.* IDRC, Ottawa.

Nweke, F.I., Ugwu, B.O., Asadu, C.L.A., & Ay, P. (1991).Production costs in the yam-based cropping systems of south-eastern Nigeria. *RCMP Research Monograph, No. 6.* IITA, Ibadan, Nigeria. 29pp.

Nwoke, F.I.O., Njoku, E., and Okonkwo, S.N.C. (1973) The effect of size of seed yams on yield of individual plants of *Dioscorea rotundata, 3rd Int. Symp. Trop, Root Crops,* Ibadan, Nigeria.

Nyman L.P. and Arditti, J. (1984) Production of salt-tolerant tissue and plantlets of taro. In: Chandra, S. (Ed.) *Edible aroids*, Clarendon, Oxford. pp 178-185.

Nystrom, L.W., Shrum, J.E. and Dawson, R.F. (1973) A mechanical harvester for *Dioscorea* composita, *3rd Int. Symp. Trop. Root Crop,* Ibadan, Nigeria.

O'Brien, P.J. (1972) The sweet potato; its origin and dispersal, *Am. Anthropologist,* **74:** 342-365.

Ojo, I.O. (1969) *Trainees' project in Yam production,* Ministry of Agriculture and Natural Resources, Ibadan, Nigeria.

Okamoto, S. (1967) The effect of potassium nutrition on the glycolysis and the krebs cycle in taro plants. *Soil Sci. Pl. Nutr.* **15**: 274-279.

Okamoto, S. (1969) The respiration in leaf discs from younger taro plants under a moderate potassium deficiency. *Soil Sci. Pl. Nutr.* **15**: 274-279.

Okoli, O.O., Igbokwe, M.C., Ene, L.S.O., and Nwokoye, C. (1982) Rapid multiplication of yam by the minisett technique. *Research Bulletin No. 2,* NRCRI, Umudike, Nigeria.

Okonkwo, S.N.C., Nwoke, F.I.O., and Njoku, E. (1973) Effect of age on the development of node cuttings of *Dioscorea bulbifera* L., *3rd Int. Symp. Trop. Root Crops*, Ibadan, Nigeria.

Olayide, S.O. (1972) Agricultural productivity and increased food production under economic development in Nigeria, *Proc. Annual Conf. Nigerian Econ. Soc., 1972.*

Onochie, B.E. (1974) Critical period for weed control in yam plots, *Niger, Agric. J.*, **11**, **(3):** 13-16.

Onwueme, I.C. (1972) Influence of the weight of the planted tuber on the vegetative performance of white yam (*Dioscorea rotundata* Poir) plants, *Niger. Agric. J.*, **9:** 170-173.

Onwueme, I.C. (1973) The sprouting process in yam (*Dioscorea* spp.) tuber pieces, *J. Agric. Sci., Camb.*, **81:** 375-379.

Onwueme, I.C. (1974) Leaf area development in white yam (*Dioscorea rotundata* Poir), as affected by coconut milk and kinetin treatment, *Niger. Agric. J.*, **11:** 17-22.

Onwueme, I.C. (1975a) Influence of storage time on earliness of sprouting and tubering in *Dioscorea rotundata* yams, *J. Agric. Sci., Camb*, **84:** 503-505.

Onwueme, I.C. (1975b) Tuber formation in yam (*Dioscorea* spp.): effect of moisture stress; contribution of the parent sett, *J. Agric. Sci., Camb.*, **85:** 267-269.

Onwueme, I.C. (1975c) Temperature effects on yam sprouting, *Proc. Agric. Soc., Nigeria*, **12:** 18.

Onwueme, I.C. (1976) Performance of yam (*Dioscorea* spp). setts planted without water, *J. Agric. Sci., Camb.*, **85:** 413-415.

Onwueme, I.C. (1977a) Field comparison of West African planting and harvesting practices in yam (*Dioscorea rotundata*): pre-sprouting, dry season planting, and double-harvesting, *J. Agric. Sci., Camb.*, **88:** 311-318.

Onwueme, I.C. (1977b) Effect of varying the time of the first-harvest, and of late planting, on double-harvest yield of yam (*Dioscorea rotundata*) in field plots, *J. Agric. Sic. Camb.*, **88:** 737-741.

Onwueme, I.C. (1978a) Evaluation of the performance of cassava (*Manihot esculenta* Crantz) when grown from inverted stem cuttings. *J. Agric. Sci. Camb.* **90**:149-156.

Onwueme, I.C. (1978b) Sett weight effects on time of tuber formation and on tuber yield characteristics, in water yam (*Dioscorea alata* L.). *J. Agric. Sci. Camb.* **91:** 317-319.

Onwueme, I.C. (1981) A delivery system for cassava in Nigeria. *Proc. 5th National Cassava Workshop*, Umudike, Nigeria. 1981.

Onwueme, I.C. (1984) Yam. In: Goldsworthy, P.R. & Fisher, N.M. (Ed.) *The physiology of tropical field crops*. Wiley, Chichester.

Onwueme, I.C. (1985) The performance of maize/yam intercrop grown with reduced labour input, using herbicidal weed control and no stakes. *Proc. 7th. Symp. Int. Soc. Trop. Root Crops*, Guadeloupe, 1985.

Onwueme, I.C. (1988) Technological advances and potential of root and tuber crops in Africa. *Proc. 8th Symp. Int. Soc. Trop. Root Crops* (Bangkok), pp 20-31.

Onwueme, I.C. (1989) A critical analysis of the yam minisett technique and its adoption by farmers in Nigeria. In: *Roots, tubers and legumes: Potential and limits for bridging nutrition gaps and food shortages in African countries*. DSE/CTA, Feldafing, Germany. pp 126-136.

Onwueme, I.C. & Fadayomi, O. (1980) A labour-saving system of yam production through weed control with herbicides, the elimination of staking, and cropping at high density. *J. Agric. Sci., Cambridge* **95**: 641-654.

Oyenuga, V.A. (1968) *Nigeria's foods and feeding stuffs.* University of Ibadan Press, Ibadan, Nigeria. 99 pp.

Oyolu, C. (1961) Is Nigeria a true agricultural country? *Niger. Scientist*, **11**: 38-47.

Passam, H.C., Read, S.J., and Rickard, J.E. (1976a) Wound repair in yam tubers: Physiological processes during repair. *New Phytologist* **77**: 325-331.

Passam, H.C., Read, S.J., and Rickard, J.E. (1976b) Wound repair in yam tubers: the dependence of storage procedures on the nature of the wound and its repair. *Trop. Sci.* **18**: 1-11.

Pena, R.S. de la, (1967) Effect of different levels of N, P, and K fertilization on the growth and yield of upland and lowland taro (*Colocasia esculenta* (L.) Schott, cv Lehua) . *Diss. Abstracts* 28 (No. 5) 1758-B.

Pena, R.S. de la, and Plucknett, D.L. (1967) The response of taro (*Colocasia esculenta* (L.) Schott) to N, P, and K fertilization under upland and lowland conditions in Hawaii. *Proc. 1st Int. Symp. Trop. Root Crops* 70-85.

Pena, R.S. de la, Plucknett, D.L., and Shibao, G.H. (1971) Application of herbicide through irrigation water for weed control in lowland taro (*Colocasia esculenta*). *Proc. Asian Pacific Weed Sci. Soc.* No. 3. 2pp.

Phillips, T.A. (1964) *An agricultural notebook*, Longman, Nigeria, Ikeja, 248 pp.

Plucknett, D.L., Ezumah, H.C., & Pena, R.S. de la, (1973) Taro (*Colocasia esculenta*) mechanization experiments in Hawaii. *3rd Int. Symp. Trop. Root Crops*, Ibadan, Nigeria.

Posthumus, A.C. (1973) Environmental factors affecting tuberization, *3rd Int. Symp. Trop. Root Crops*, Ibadan, Nigeria.

Potty, V.P. (1991) Management of VAMF in sweet potato. *Proc. 9th Symp. Int. Soc. Trop. Root Crops*, Accra, 1991.

Purcel, J.G. and Williams, D.H. (1973) History of the development of the first mechanized continuous *gari* manufacturing plant, *3rd Int. Symp. Trop. Root Crops*, Ibadan, Nigeria.

Purewal, S.S., and Dargan, K.S. (1957) Effects of spacing on development and yield of arum (*Colocasia esculenta*). Indian *J. Agric. Sci.* **27:** 151-162.

Purseglove, J.W. (1968) *Tropical Crops. Dicotyledons 1,* Longmans Green and Co., London, 332 pp.

Purseglove, J.W. (1972) *Tropical crops. Monocotyledons,* Longmans, London.

Raghavan, R.S. (1958) A chromosome survey of Indian Dioscoreas, *Proc. Indian Acad. Sci., Sect. B,* **48:** 59-63.

Rodriguez, N.F., and Sanchez de Bustamante, C.A. (1963) Importance of the type of cuttings for the production of cassava in Missiones, *Rev. Invest. Agric., Buenos Aires,* **17:** 289-302.

Rogers, D.J. (1963) Studies of *Manihot esculenta* Crantz (Cassava) and related species, *Bull. Torrey Bot.,* **90:** 43-54.

Sammy, G.M. (1973) The status of root erop research at the University of the West Indies, St. Augustine, *3rd Int. Symp. Trop. Root Crops,* Ibadan, Nigeria.

Sanchez de Bustamante, C.A. and Rodriguez, N.F. (1967) Winter storage of cassava stems for use as cut setts in Missiones province, *Rev. Invest. Agropec., Ser. 2,* **4:** 331-349.

Satoh, I., and Tanabe, K. (1971) Studies on the use of MH (maleic hydrazide) in the cultivation of Chinese yams (*Dioscorea batatas*). *Bulletin of the Faculty of Agriculture, Tottori University,* **23:** 47-52.

Schlimme, D.V. (1966) Anatomical and physiological aspects of sprout initiation and development in sweet potato storage roots, *Diss. Abstracts,* **26** (No. 9), 4947.

Scott, L.E. (1950) Potassium uptake by the sweet potato plant, *Proc. Am. Soc. Hort. Sci.* **56:** 248-252.

Shanmugavelu, K.G., Thamburaj, S., Shanmugam, A., and Gopalaswamy, N. (1972) Effect of time of planting and type of planting material on the yield of sweet potato (*Ipomoea batatas*), *South India Horticulture,* **20:** 55-58.

Sieverding, E. (1988) Effect of soil temperature on performance of different VA mycorrhizal isolates with cassava. *Angewandte Botanik* **62**: 295-300.

Silva, J.R. Da (1971) Cassava research programme in Brazil, *Agronomico,* **23:** 33-48.

Silvestre, P. (1989) *Cassava.* CTA/MacMillan, London. 82pp.

Singh, S.R. (1973) Host range and vector relationship of cassava mosaic, *3rd Int. Symp. Trop. Root Crops,* Ibadan, Nigeria.

Sinha, S.K. (1969) Cyanogenic glucoside production and its possible control in cassava, *Indian J. Pl. Physiol.,* **12:** 140-147.

Sinha, S.K. and Nair, T.V. (1968) Studies on the variability of cyanogenic glucoside content in cassava tubers, *Indian J. Agric. Sc.,* **38**: 958-963.

Sobulo, R.A. (1972) Studies on white yam (*Dioscorea rotundata*) I. Growth analysis, *Exp. Agric.,* **8:** 99-106.

Spence, J.A. (1970) Growth and development of tannia (*Xanthosoma* spp.) *Proc. 2nd Int. Symp. Trop. Root Crops* 11:47-52

Spence, J.A. and Ahmad, N. (1967) Plant nutrient deficiencies and related tissue composition of tannia (*Xanthosoma sagittifolium*) *1st Int. Symp. Trop. Root Crops*.11: 61-69.

Spence, J.A. and Ahmad, N. (1967) Plant nutrient deficiencies and related tissue composition of the sweet potato, *Agron. J.*, **59:** 59-62.

Steele, W., and Sammy, G.M. (1973) Instant dehydrated yam, *3rd Int. Symp. Trop. Root Crops,* Ibadan, Nigeria.

Su, K.C., Tseng, S.T., and Wang, Y.K. (1965) Effect of planting methods of cuttings and carbon dioxide treatment of tubers on the seed multiplication of sweet potato, *J. Agric. Ass. China,* **50:** 42-46

Subramaniam, T.R., Rao, P.V.S., and Gopalaswamy, M. (1973) Evaluation of certain new insecticides in the control of the sweet potato weevil, *Cylas formicarius, Madras Agric. J.,* **60:** 621.

Takyi, S.K. (1974) Effects of nitrogen, planting method, and seedbed type on yield of cassava (*Manihot esculenta* Crantz), *Ghana J. Agric. Sci.,* **7:** 69-73.

Talbert, R.E. (1967) Weed control in sweet potatoes, *Arkansas Farm Res.,* **16:** 13.

Terauchi, R., Chikaleke, V.A., Thottappilly, G., & Hahn, S.K. (1992) Origin and phylogeny of the Guinea yam as revealed by RFLP analysis of chloroplast DNA and nuclear ribosomal DNA. IITA, Ibadan, Nigeria.

Tompkins, D.R., Horton, R.D., and Sistrunk, W.A. (1973) Sprouting of sweet potatoes treated with ethephon or gibberellic acid, *Arkansas Farm Res.,* **22:** 10.

Tono, T. (1968) Food chemical studies on the Chinese yam. 2. Analysis of glycoproteins and free amino acids by using amino acid analyzer. *Trans Tottori Soc, Agric. Sci.* **20**: 129-135.

Treche, S., and Delpeuch, F. (1979) [Evidence for the development of a membrane thickening in the parenchyma of tubers of *Dioscorea dumetorum* during storage] *C.R.Hebd. Seanc. Acad. Sci.,* D **288**: 67-70.

Trujillo, E.E., & Aragani, M. (1964) Taro blight and its control. *Hawaii Farm Sci.* **13**: 11-13.

Tsuno, Y. and Fujise, K. (1968) Studies on the dry mater production of sweet potato 10. An explanation of determination of dry matter percentage in tuber from the viewpoint of nutrient conditions and dry matter production. *Proc. Crop. Sci. Soc. Japan,* **37:** 12-16.

Udeubo, A.E. (1971) Effect of external supply of growth substances on axillary proliferation and development in *D. bulbifera, Ann. Bot.,* **35:** 159-163.

Umanah, E.E. (1973) Effect of different rates of NPK fertilizers on yield and storage properties of white yam (*Dioscorea rotundata* L.), *3rd Int. Symp. Trop. Root Crops,* Ibadan, Nigeria.

U.S.D.A. (United States Department of Agriculture) (1972) Yam production methods, *Production Research Report No. 147.*

U.S.D.A. (United States Department of Agriculture)(1974a) Tropical Yams and their Potential Part 1 *Dioscorea esculenta, Agriculture Handbook No. 457.*

U.S.D.A. (United States Department of Agriculture)(1974b) Tropical Yams and their Potential Part 2 *Dioscorea bulbifera, Agriculture Handbook No. 466.*

Vijayan, M.R., and Aiyer, R.S. (1969) Effect of nitrogen and phosphorus on the yield and quality of cassava, *Agric. Res. Jnl. Keralà,* **7:** 84-90.

Wadhwa, N.D. (1973) Cassava gari plant, *3rd Int. Symp. Trop. Root Crops,* Ibadan, Nigeria.

Waitt, A.W. (1960) Yam trials, *Rep. Dept. Agric. Res., Nigeria,* 1958-59, pp13-14.

Waitt, A.W. (1961a) Key to some Nigerian yam varieties, *Memo Fed. Dept. Agric. Res., Nigeria.*

Waitt, A.W. (1961b) Yams, *Rep. Dept. Agric. Res., Nigeria,* 1959-60, pp16-19.

Waitt, A.W. (1963) Yams, *Dioscorea* species, *Field Crop Abstracts,* **16:** 145-157.

Walker, H.M. (1961) The sealed storage of yams, *Rep. W. Afr. Stored Prod. Res. Unit.,* 1961, pp103-106.

Wang, J.(1983) *Taro - A review of* Colocasia esculenta *and its potentials.* University of Hawaii Press, Honolulu. 400pp.

Wareing, P. F. (1973) Hormones and tuberization, *3rd Int. Symp. Trop. Root Crops,* Ibadan, Nigeria.

Watanabe K., Ozaki, K., and Yashiki, T. (1968) Studies on the effect of soil physical condition on the growth and yield of crop plants 7. Effect of soil air composition and soil bulk density on the growth of sweet potato, *Proc. Crop Sci. Soc. Japan,* **37:** 65-69.

Welch, N.C., and Little, T.M. (1966) The effect of heating and cutting roots on sweet potato sprout production, *Proc. Am. Soc. Hort. Sci.,* **88:** 477-480.

Whatley, B.T. (1969) The effect of root sectioning and chemicals on sweet potato plant production, *J. Am. Soc. Hort. Sci.,* **94:** 179-180.

Wholey, D.W., and Cock, J.H. 91973) A rapid method of the propagation of cassava, *3rd Int. Symp. Trop. Root Crops,* Ibadan, Nigeria.

Williams, C.N., and Ghazali, S.M. (1969) Growth and productivity of tapioca (*Manihot utilissima*) 1. Leaf characteristics and yield, *Exp. Agric.,* **5:** 183-194.

Wilson, J.E. (1979) Promotion of flowering and production of seed in cocoyam, *Xanthosoma* and *Colocasia. Proc. 5th Symp. Int Soc. Trop. Root Crops.* Manila, 1979.

Wilson, J.E. (1980) Cocoyam breeding by flower induction, pollination, and seed germination. *Manual Series No. 4* , IITA, Ibadan, Nigeria.

Wilson, J.E., Sivan, P. & Monroe, C. (1991) Alafua Sunrise and Samoa Hybrid improve the production of taro (*Colocasia esculenta* (L.) Schott) in the Pacific. *Proc. 9th Symp., Int. Soc. Trop. Root Crops, Accra*, 1991.

Wilson, L.A., and Lower, S.B. (1973a) Quantitative morphogenesis of root types in the sweet potato (*Ipomoea batatas* (L.) Lam) root system during early growth from stem cuttings, *Trop. Agric.,* **50:** 343-345.

Wilson L.A. and Lowe, S.B. (1973b) Development of supplementary translocatory tissues in intact and *Megastes*-infested tuber stalks of sweet potato (*Ipomoea batatas* (L.) Lam), *J. Hort. Sci.,* **48:** 223-226.

Wilson, B.J., Yang, D.T.C., and Boyd, M.R. (1970) Toxicity of mould-damaged sweet potatoes (Ipomoea batatas) Nature, Lond., **227**:521-522.

Yaniek, J.S. and Animashaun, A. (1987) Why cassava green mites are dry season pests. In: Rijks, D. and Malthys, G. (Ed.) *Seminar on agrometeorology and crop protection in the lowland humid and subhumid tropics, Cotonou, Benin, 1987. Proc., World Met. Org.* pp 59-67.

INDEX

INDEX

Aerial yam
Age
 of cassava stem cutting,
 physiological, of yam tuber, etc.
Alkaloids, in yam tuber,
Alocasia,
Amorphophallus,
Anthracnose
 on cassava,
 on yam,
Aroids, edible,

Bacterial blight, cassava,
Baked yam,
Barns, for yam storage,
Beetles
 yam,
Bemisia tabaci,
Bitter varieties, of cassava,
Black rot, of sweet potato,
Boiled yam,
Botany
 of cassava,
 of cocoyams,
 of sweet potato,
 of yam,
Botrydiplodia,
Breeding
 of cassava,
 of cocoyams,
 of sweet potato,
 of yam,
Brown leaf spot, of cassava,
Bulbils
 of yam,
 propagation by,
 structure,
Bush-fallow,

Carbohydrate content
 of cassava,
 of sweet potato,
 of tannia,
 of taro,of yam,
Cassava anthracnose,
Cassava bacterial blight,
Cassava chips,
Cassava flour,
Cassava green mite
Cassava mosaic disease,
Cassava pellets,
Ceratocystis fimbriata,
Cercospora,
Chemical composition, (*see* Composition)
Chickwangue,
Chinese yam,
Chips
 of cassava,
 of sweet potato,
 of yam,
Chromosome numbers
 of cassava,
 of sweet potato,
 of tannia,
 of taro,
 of yam,
Cinnamon yam,
Cladosporium leaf spot, of taro
Classification
 of cassava,
 of sweet potato,
 of tannia,
 of taro,
 of yam,
Cork formation, on yam tuber,
Corm
 of tannia,
 of taro,
 of yam,

Cormel
 of tannia,
 of taro,
Crop improvement, (*see* Improvement)
Cropping systems
 for cassava,
 for cocoyams,
 for sweet potato,
 for yam,
Cultivars
 of cassava,
 of sweet potato,
 of tannia,
 of taro,
 of yam,
Curing
 of sweet potato,
 of yam,
Cush-cush yam,
Cutting, stem,
 of cassava,
 of cocoyams,
 of sweet potato,
 of yam,
Cyanide, in cassava
Cyanogenic glucoside
 in cassava,
 in taro,
Cylas,(*see* Sweet potato weevil)
Cyrtosperma,

Deficiency symptoms
 in cassava,
 in sweet potato,
 in tannia,
 in taro,
Deficiency symptoms (*contd)*
 in yam,
Depth of planting
 for cocoyams,
 for yam,
Dioscorea alata,
Dioscorea bulbifera,
Dioscorea cayenensis,
Dioscorea dumetorum,
Dioscorea esculenta,
Dioscorea hispida,
Dioscorea japonica,
Dioscorea opposita,
Dioscorea rotundata,
Dioscorea trifida,
Dioscorine,
Diosgenin,
Diseases
 of cassava,
 of sweet potato
 of tannia,
 of taro,
 of yam,
Dominance, proximal
 in sweet potato,
 in yam,
Dormancy
 in cassava seed,
 in sweet potato seed,
 in yam tuber,
Double harvesting,
Drought tolerance
 in cassava,
 in yam,
Dry matter content
 of cassava,
 of sweet potato,
 of tannia,
Dry matter content (*contd*)
 of taro,
 of yam,
Dry rot, of yam
Dry season planting of yam,

Eba,
Ecology
 of cassava,
 of cocoyams,

of sweet potato,
of yams,
Economic importance
 of cassava,
 of cocoyams,
 of sweet potato,
 of yam,
Elephant yam,
Emergence,
Environmental conditions
 for cassava,
 for cocoyams,
 for sweet potato,
 for yam,

Farinha,
Feathery mottle complex,
Feed
 cassava as,
 sweet potato as,
 yam as,
Fertilizer
 for cassava,
 for sweet potato,
 for tannia,
 for taro,
 for yam,
First harvest, of yam,
Flakes, yam,
Flat planting,
 of cassava,
Flat planting (*contd*)
 of yam,
Flower
 of cassava,
 of sweet potato,
 of tannia,
 of taro,
 of yam,
Flowering
 in cassava,
 in sweet potato
 in taro,
 in yam,
Fresh tuber
 of cassava,
 of sweet potato,
 of yam,
Fried yam,
Fried yam-balls,
Fruit
 of cassava,
 of sweet potato,
 of tannia,
 of taro,
 of yam,
Fungal diseases
 of cassava,
 of sweet potato,
 of tannia,
 of taro,
 of yam,
Fusarium,
Future
 of cassava,
 of cocoyams,
 of sweet potato,
 of yam

Gari,
Germination, seed
 of cassava,
 of sweet potato,
 of taro,
 of yam,
Giant taro,
Glomerella,
Glucoside, cyanogenic,
Grasshopper, variegated,
Greater yam (*see Dioscorea alata*)
Growth cycle
 of cassava,
 of cocoyams,
 of sweet potato,

 of yam,
Growth of yam tuber

Harvesting
 of cassava,
 of cocoyams,
 of sweet potato,
 of yam bulbils,
 of yam tuber,
Heads, of yam,
Heaving, in yam,
Herbicides for weed control
 in cassava,
 in cocoyams,
 in sweet potato,
 in yam,
Holes, for yam planting,
Horizontal placement, of cassava cutting,
Hybridization,
Hydrocyanic acid,

Importance (*see* Economic importance)
Improvement
 of cassava
 of cocoyams,
 of sweet potato,
Improvement (*contd*)
 of yam,
Incompatibility, in sweet potato,
Index of maturity, in yam,
Individual staking, of yam,
Industrial uses
 of cassava,
 of sweet potato
 of yam,
Insect pests
 of cassava,
 of cocoyams,
 of sweet potato,
 of yam,
Internal cork disease,

Labour
 in cassava production,
 in cocoyam production,
 in sweet potato production
 in yam production
Leaf
 of cassava
  as food,
  composition,
  structure,
 of sweet potato
  as food,
  composition,
  structure,
 of tannia
  as food,
  composition,
  structure
 of taro
  as food
  composition
  structure
 of yam
Leaf spot
Length, of cassava cutting,
Length of growing season
 for cassava,
 for cocoyams,
 for sweet potato,
 for yam,
Lesser yam,
Light intensity, influence on yam growth,
Linamarase,
Linamarin,
Lotaustralin,

Mammalian pests
 of cassava,
 of yam,
Manihot esculenta,
Mashed yam,
Maturity index, for yam,

Meal of retted cassava,
Mealy bugs
  on cassava,
  on yam,
Middles, of yam,
Minisett
  of yam,
  of cocoyams,
Mites on cassava,
Moisture content
  of cassava,
  of sweet potato,
  of tannia,
  of taro,
  of yam,
Moisture stress,

Mosaic disease
  of cassava,
  of sweet potato,
Mounds,
Mulching
  for cocoyams,
  for yam,

Nematodes
  on cassava,
  on sweet potato,
  on yam,
New-yam festivals,
Nitrogen fertilizer,

Orientation
  of cassava cutting,
  of yam sett,
Origin
  of cassava,
  of sweet potato,
  of tannia,
  of taro,
  of yam,
Pellets, cassava,
Phosphorus fertilizer,
Photoperiodism
  in cassava tubering,
  in sweet potato flowering,
  in sweet potato tubering,
  in yam tubering,
Physiological age, of yam tuber,
Phytophthora colocasiae,
Planting
  of cassava,
    time of,
  of cocoyams,
    time of,
  of sweet potato,
    time of,
  of yam,
    time of,
Planting material
  for cassava,
  for cocoyams,
  for sweet potato,
  for yam,
Platform storage
  of sweet potato,
  of yam,
Poi,
Potassium fertilizer,
Pounded yam,
Presprouting
  of sweet potato,
  of yam,
Problems
  in cassava,
  in cocoyams,
  in sweet potato,
  in yam,
Processed forms
  of cassava,
  of cocoyams,
  of sweet potato,
  of yam,

Production, (*see* World production)
Propagation
  of cassava,
  of cocoyams,
  of sweet potato,
  of yams,
Protein content
  of cassava
  of sweet potato,
  of tannia,
  of taro,
  of yam,
Proximal dominance,
Pyramidal staking of yam,

Retted cassava, meal of,
Re-tuberization, in yam,
Ridging,
Roasted yam,
Root knot nematode
  on cassava,
  on sweet potato,
  on taro,
  on yam,
Root system
  of cassava,
  of sweet potato,
  of tannia,
  of taro,
  of yam,
Rooting
  of cassava stem,
  of sweet potato vine,
  of yam vine,
Root rot
  of cocoyams,
  of yam,
Rosellinia,
Rotation, crop (*see* Cropping systems)
Rots,
  of cassava,
  of cocoyams,
  of sweet potato,
  of yam,

Sclerotium rot,
Scurf,
Scutellonema bradys,
Second harvest,
Seed
  of cassava,
  of sweet potato,
  of tannia,
  of taro,
  of yam,
Seed production
  in cassava,
  in cocoyams,
  in sweet potato,
  in yam,
Seedbed preparation
  for cassava,
  for cocoyams,
  for sweet potato,
  for yam,
Seedling
  of cassava,
  of sweet potato,
  of yam,
Selection,
Sett orientation,
Sett placement,
Sett size,
Sett type,
Shape
  of cassava tuber,
  of cocoyam corm,
  of cocoyam cormel,
  of sweet potato tuber,
  of yam tuber,
Shifting cultivation,
Single harvesting,
Soft rot
  of sweet potato,

 of tannia,
 of taro,
 of yam,
Spacing
 of cassava,
 of cocoyams,
 of sweet potato,
 of yam,
Sprouting
 as affected by physiological age,
 in storage,
 of yam tuber,
Staking,
Starch
 in cassava,
 in sweet potato,
 in tannia,
 in taro,
 in yam,
Stem cutting, (*see* Cutting, stem)
Stem structure
 of cassava,
 of sweet potato,
 of yam,
Storage
 of cassava,
 of cocoyams,
 of sweet potato,
 of yam,
Storage losses, in yam,
Sugars
 in sweet potato
 in taro,
 in yam
Sweet potato virus disease complex,
Sweet potato weevil,
Sweet varieties, of cassava,
Tails, of yam,
Tapioca,
Taro leaf blight,
Taro leafhopper,
Taro soft rot,
Time of planting
 for cassava,
 for cocoyams,
 for sweet potato,
 for yam,
Tissue culture,
Trade
 in cassava,
Trade (*contd.*)
 in cocoyams,
 in sweet potato,
 in yam,
Trellis, for yam staking,
Trenches, for yam planting,
Tuber rots,
Tubers
 dormancy,
 formation,
 growth,
 shape,
 sprouting,
 structure,

Underground storage,
Upland culture, of taro and tannia,
Utilization
 of cassava,
 of cocoyams,
 of sweet potato,
 of yam bulbil,
 of yam tuber,

Variegated grasshopper,
Varieties (*see* Cultivars)

Vine cuttings
 of sweet potato,
 of yam,
Virus diseases
 of cassava,
 of sweet potato,
 of yam,

Vitamins
  in cassava,
  in sweet potato,
  in tannia,
  in taro,
  in yam,

Water yam,
Weed control
  in cassava,
  in cocoyams,
  in sweet potato,
  in yam
White fly,
White guinea yam,
White yam,
Wholes,
Wood ash,
World production
  of cassava,
  of cocoyams,
  of sweet potato,
  of yam,

Xanthomonas manihotis,

Yam anthracnose
Yam beetle,
Yam chips,
Yam festivals,
Yam flakes,
Yam flour,
Yam nematode,
Yam-balls, fried,
Yams, kinds of,
Yellow guinea yam,
Yellow yam,
Yields
  of cassava,
  of cocoyams,
  of sweet potato,
  of yam,

Zonocerus,

FAO TECHNICAL PAPERS

FAO PLANT PRODUCTION AND PROTECTION PAPERS

1 Horticultura: a select bibliography, 1976 (E)
2 Cotton specialists and research institutions in selected countries, 1976 (E)
3 Food legumes: distribution, adaptability and biology of yield, 1977 (E F S)
4 Soybean production in the tropics, 1977 (C E F S)
4 Rev.1 Soybean production in the tropics (first revision), 1982 (E)
5 Les systèmes pastoraux sahéliens, 1977 (F)
6 Pest resistance to pesticides and crop loss assessment – Vol. 1, 1977 (E F S)
6/2 Pest resistance to pesticides and crop loss assessment – Vol. 2, 1979 (E F S)
6/3 Pest resistance to pesticides and crop loss assessment – Vol. 3, 1981 (E F S)
7 Rodent pest biology and control – Bibliography 1970–74, 1977 (E)
8 Tropical pasture seed production, 1979 (E F** S**)
9 Food legume crops: improvement and production, 1977 (E)
10 Pesticide residues in food, 1977 – Report, 1978 (E F S)
10 Rev. Pesticide residues in food 1977 – Report, 1978 (E)
10 Sup. Pesticide residues in food 1977 – Evaluations, 1978 (E)
11 Pesticide residues in food 1965-78 – Index and summary, 1978 (E F S)
12 Crop calendars, 1978 (E/F/S)
13 The use of FAO specifications for plant protection products, 1979 (E F S)
14 Guidelines for integrated control of rice insect pests, 1979 (Ar C E F S)
15 Pesticide residues in food 1978 – Report, 1979 (E F S)
15 Sup. Pesticide residues in food 1978 – Evaluations, 1979 (E)
16 Rodenticides: analyses, specifications, formulations, 1979 (E F S)
17 Agrometeorological crop monitoring and forecasting, 1979 (C E F S)
18 Guidelines for integrated control of maize pests, 1979 (C E)
19 Elements of integrated control of sorghum pests, 1979 (E F S)
20 Pesticide residues in food 1979 – Report, 1980 (E F S)
20 Sup. Pesticide residues in food 1979 – Evaluations, 1980 (E)
21 Recommended methods for measurement of pest resistance to pesticides, 1980 (E F)
22 China: multiple cropping and related crop production technology, 1980 (E)
23 China: development of olive production, 1980 (E)
24/1 Improvement and production of maize, sorghum and millet – Vol. 1. General principles, 1980 (E F)
24/2 Improvement and production of maize, sorghum and millet – Vol. 2. Breeding, agronomy and seed production, 1980 (E F)
25 *Prosopis tamarugo:* fodder tree for arid zones, 1981 (E F S)
26 Pesticide residues in food 1980 – Report, 1981 (E F S)
26 Sup. Pesticide residues in food 1980 – Evaluations, 1981 (E)
27 Small-scale cash crop farming in South Asia, 1981 (E)
28 Second expert consultation on environmental criteria for registration of pesticides, 1981 (E F S)
29 Sesame: status and improvement, 1981 (E)
30 Palm tissue culture, 1981 (C E)
31 An eco-climatic classification of intertropical Africa, 1981 (E)
32 Weeds in tropical crops: selected abstracts, 1981 (E)
32 Sup.1 Weeds in tropical crops: review of abstracts, 1982 (E)
33 Plant collecting and herbarium development, 1981 (E)
34 Improvement of nutritional quality of food crops, 1981 (C E)
35 Date production and protection, 1982 (Ar E)
36 El cultivo y la utilización del tarwi – *Lupinus mutabilis* Sweet, 1982 (S)
37 Pesticide residues in food 1981 – Report, 1982 (E F S)
38 Winged bean production in the tropics, 1982 (E)
39 Seeds, 1982 (E/F/S)
40 Rodent control in agriculture, 1982 (Ar C E F S)
41 Rice development and rainfed rice production, 1982 (E)
42 Pesticide residues in food 1981 – Evaluations, 1982 (E)
43 Manual on mushroom cultivation, 1983 (E F)
44 Improving weed management, 1984 (E F S)
45 Pocket computers in agrometeorology, 1983 (E)
46 Pesticide residues in food 1982 – Report, 1983 (E F S)
47 The sago palm, 1983 (E F)
48 Guidelines for integrated control of cotton pests, 1983 (Ar E F S)
49 Pesticide residues in food 1982 – Evaluations, 1983 (E)
50 International plant quarantine treatment manual, 1983 (C E)
51 Handbook on jute, 1983 (E)
52 The palmyrah palm: potential and perspectives, 1983 (E)
53/1 Selected medicinal plants, 1983 (E)
54 Manual of fumigation for insect control, 1984 (C E F S)
55 Breeding for durable disease and pest resistance, 1984 (C E)
56 Pesticide residues in food 1983 – Report, 1984 (E F S)
57 Coconut, tree of life, 1984 (E S)
58 Economic guidelines for crop pest control, 1984 (E F S)
59 Micropropagation of selected rootcrops, palms, citrus and ornamental species, 1984 (E)
60 Minimum requirements for receiving and maintaining tissue culture propagating material, 1985 (E F S)
61 Pesticide residues in food 1983 – Evaluations, 1985 (E)
62 Pesticide residues in food 1984 – Report, 1985 (E F S)
63 Manual of pest control for food security reserve grain stocks, 1985 (C E)
64 Contribution à l'écologie des aphides africains, 1985 (F)

65 Amélioration de la culture irriguée du riz des petits fermiers, 1985 (F)
66 Sesame and safflower: status and potentials, 1985 (E)
67 Pesticide residues in food 1984 – Evaluations, 1985 (E)
68 Pesticide residues in food 1985 – Report, 1986 (E F S)
69 Breeding for horizontal resistance to wheat diseases, 1986 (E)
70 Breeding for durable resistance in perennial crops, 1986 (E)
71 Technical guideline on seed potato micropropagation and multiplication, 1986 (E)
72/1 Pesticide residues in food 1985 – Evaluations – Part I: Residues, 1986 (E)
72/2 Pesticide residues in food 1985 – Evaluations – Part II: Toxicology, 1986 (E)
73 Early agrometeorological crop yield assessment, 1986 (E F S)
74 Ecology and control of perennial weeds in Latin America, 1986 (E S)
75 Technical guidelines for field variety trials, 1993 (E S)
76 Guidelines for seed exchange and plant introduction in tropical crops, 1986 (E)
77 Pesticide residues in food 1986 – Report, 1986 (E F S)
78 Pesticide residues in food 1986 – Evaluations – Part I: Residues, 1986 (E)
78/2 Pesticide residues in food 1986 – Evaluations – Part II: Toxicology, 1987 (E)
79 Tissue culture of selected tropical fruit plants, 1987 (E)
80 Improved weed management in the Near East, 1987 (E)
81 Weed science and weed control in Southeast Asia, 1987 (E)
82 Hybrid seed production of selected cereal, oil and vegetable crops, 1987 (E)
83 Litchi cultivation, 1989 (E S)
84 Pesticide residues in food 1987 – Report, 1987 (E F S)
85 Manual on the development and use of FAO specifications for plant protection products, 1987 (E F S)
86/1 Pesticide residues in food 1987 – Evaluations – Part I: Residues, 1988 (E)
86/2 Pesticide residues in food 1987 – Evaluations – Part II: Toxicology, 1988 (E)
87 Root and tuber crops, plantains and bananas in developing countries – challenges and opportunities, 1988 (E)
88 *Jessenia* and *Oenocarpus*: neotropical oil palms worthy of domestication, 1988 (E S)
89 Vegetable production under arid and semi-arid conditions in tropical Africa, 1988 (E F)
90 Protected cultivation in the Mediterranean climate, 1990 (E F)
91 Pastures and cattle under coconuts, 1988 (E S)
92 Pesticide residues in food 1988 – Report, 1988 (E F S)
93/1 Pesticide residues in food 1988 – Evaluations – Part I: Residues, 1988 (E)
93/2 Pesticide residues in food 1988 – Evaluations – Part II: Toxicology, 1989 (E)
94 Utilization of genetic resources: suitable approaches, agronomical evaluation and use, 1989 (E)
95 Rodent pests and their control in the Near East, 1989 (E)
96 *Striga* – Improved management in Africa, 1989 (E)
97/1 Fodders for the Near East: alfalfa, 1989 (Ar E)
97/2 Fodders for the Near East: annual medic pastures, 1989 (Ar E F)
98 An annotated bibliography on rodent research in Latin America 1960-1985, 1989 (E)
99 Pesticide residues in food 1989 – Report, 1989 (E F S)
100 Pesticide residues in food 1989 – Evaluations – Part I: Residues, 1990 (E)
100/2 Pesticide residues in food 1989 – Evaluations – Part II: Toxicology, 1990 (E)
101 Soilless culture for horticultural crop production, 1990 (E)
102 Pesticide residues in food 1990 – Report , 1990 (E F S)
103/1 Pesticide residues in food 1990 – Evaluations – Part I: Residues, 1990 (E)
104 Major weeds of the Near East, 1991 (E)
105 Fundamentos teórico-prácticos del cultivo de tejidos vegetales, 1990 (S)
106 Technical guidelines for mushroom growing in the tropics, 1990 (E)
107 *Gynandropsis gynandra* (L.) Briq. – a tropical leafy vegetable – its cultivation and utilization, 1991 (E)
108 Carambola cultivation, 1993 (E S)
109 Soil solarization, 1991 (E)
110 Potato production and consumption in developing countries, 1991 (E)
111 Pesticide residues in food 1991 – Report, 1991 (E)
112 Cocoa pest and disease management in Southeast Asia and Australasia, 1992 (E)
113/1 Pesticide residues in food 1991 – Evaluations – Part I: Residues, 1991 (E)
114 Integrated pest management for protected vegetable cultivation in the Near East, 1992 (E)
115 Olive pests and their control in the Near East, 1992 (E)
116 Pesticide residues in food 1992 – Report, 1993 (E F S)
117 Quality declared seed, 1993 (E)
118 Pesticide residues in food 1992 – Evaluations – Part I: Residues, 1993 (E)
119 Quarantine for seed, 1993 (E)
120 Weed management for developing countries, 1993 (E)
121 Rambutan cultivation, 1993 (E)
122 Pesticide residues in food 1993 – Report, 1993 (E)
123 Rodent pest management in eastern Africa, 1994 (E)
124 Pesticide residues in food 1993 – Evaluations – Part I: Residues, 1994 (E)
125 Plant quarantine: theory and practice, 1994 (Ar)
128 Tropical root and tuber crops: production, perspectives and future prospects, 1994 (E)

Availability: October 1994

Ar – Arabic
C – Chinese
E – English
F – French
P – Portuguese
S – Spanish

Multil – Multilingual
* Out of print
** In preparation

The FAO Technical Papers are available through the authorized FAO Sales Agents or directly from Distribution and Sales Section, FAO, Viale delle Terme di Caracalla, 00100 Rome, Italy.

This document gives wide coverage of the production, harvesting, storage and utilization of cassava, yams, sweet potatoes and edible aroids. It brings together relevant infomation scattered in numerous textbooks, research reports, journals, bulletins and unpublished documents. The socio-economic and food policy importance of the tropical roots and tubers is particularly elaborated. The future prospects for these crops and their role in national and international food security are highlighted.

ISBN 92-5-103461-3 ISSN 0259-2517

9 789251 034613

M-11 T1848E/1/10.94/1600